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# New Concepts for Design of an Automated Hydraulic Piping Network for a Water Mist Fire Suppression System on Navy Ships

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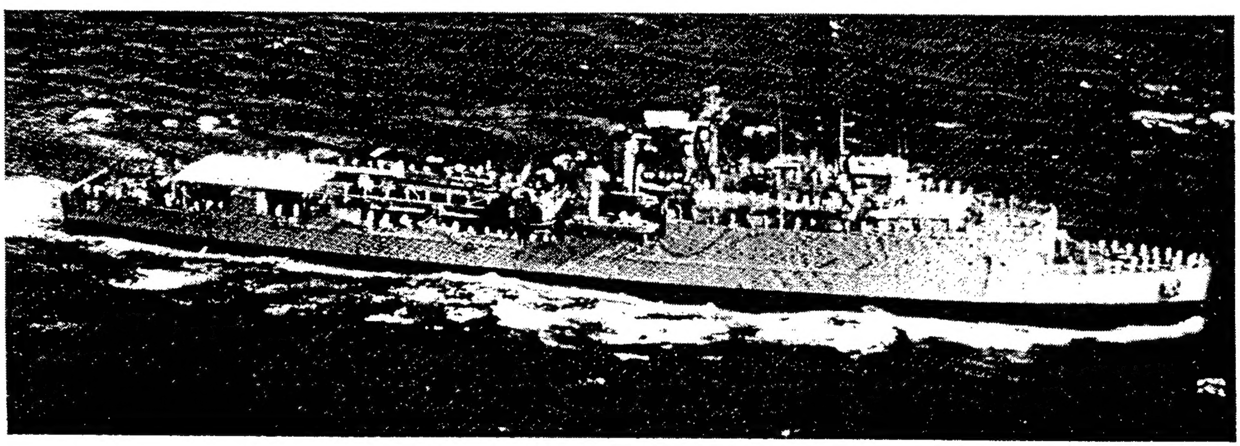

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The purpose of this report is to describe the design of an automated water distribution system to supply a ship-wide network of nozzles for fire suppression purposes, and then to explain the implementation of that design as a test platform on the ex-USS *Shadwell*. The analysis will show that the proposed system architecture has the potential to provide a higher degree of "survivability" after battle damage than believed possible with alternative distribution architectures. Dubbed "Sectional Loop," this robust architecture combines the attributes of "dual main" and "offset loop" architectures explored by others [3], and includes several advantages that are not possible with those designs. In this study, the term "survivability" after a blast event is defined in terms of the capability of the piping system to supply water to mist nozzles immediately adjacent to the primary blast damage areas.

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# NEW CONCEPTS FOR DESIGN OF AN AUTOMATED HYDRAULIC PIPING NETWORK FOR A WATER MIST FIRE SUPPRESSION SYSTEM ON NAVY SHIPS

## 1.0 INTRODUCTION

This report describes work performed in the second year of an experimental program aimed at developing a prototype water mist fire suppression system for Navy shipboard applications that is integrated with the objectives of the Damage Control for Automated Reduced Manning (DC-ARM) program. The general DC-ARM objective is to reduce manning on future Navy ships by means of automated damage control systems. The basic premise of this study is that automatic fire suppression systems will be required throughout all areas of a ship, to reduce the risk of very large fires requiring a great deal of manpower to manage. With respect to fire protection systems, full-scale fire tests were conducted in Phase I of the program to evaluate the potential for water mist to provide flashover suppression and boundary cooling benefits [1]. Phase II of the program (Year 2) involved the development of design concepts for an automated hydraulic piping water distribution system. In Phase III, the innovative concepts are to be evaluated using the full-scale test facility on the ex-USS *Shadwell* [2].

The purpose of this report is to describe the design of an automated water distribution system to supply a ship-wide network of nozzles for fire suppression purposes, and then to explain the implementation of that design as a test platform on the SHADWELL. The analysis will show that the proposed system architecture has the potential to provide a higher degree of "survivability" after battle damage than believed possible with alternative distribution system architectures. Dubbed "Sectional Loop," this robust architecture combines the attributes of "dual main" and "offset loop" architectures explored by others [3], and include several advantages that are not possible with those designs. In this study, the term "survivability" after a blast event is defined in terms of the capability of the piping system to supply water to mist nozzles immediately adjacent to the primary blast damage areas.

For active fire protection systems, the goal is to design a hydraulic distribution system that will meet the peacetime flow and pressure demands for fire suppression, as well as the emergency flow conditions associated with a battle damage scenario. The system is intended to sense the difference between "normal flow" conditions and "excess flow" conditions associated with a pipe rupture and respond "automatically" to isolate the ruptured area and return the remainder of the system to full function.

The performance objective of "flashover suppression" as opposed to "fire suppression or extinguishment" was introduced during the Year I fire testing. The fire tests demonstrated that significant reduction in compartment temperatures and limit of fire spread could be achieved using a few water mist nozzles in each compartment [1]. A fire protection system designed for flashover suppression would maintain average gas temperatures too low to ignite materials beyond the compartment of origin. It could have two to four nozzles per compartment, possibly (but not necessarily) located at compartment perimeters, and aimed horizontally into the space,

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plus nozzles in each passageway. The amount of water required to achieve flashover suppression was much less than required for standard marine sprinklers. Reduced water demand should permit reduced pipe diameters and other hardware requirements. The weight, space and cost savings could be applied toward providing more avenues for redundancy in the distribution system. This increased freedom for redundancy could then be applied to the design of a robust distribution system capable of self-diagnosis and remedy of a rupture condition. Without the reduction in pipe size and component weight afforded by using high pressure (HP) water mist, there would be much less freedom to devise an innovative water distribution system.

The Phase I report referred to flashover suppression and "boundary cooling." Boundary cooling, or more descriptively, "boundary protection," represents a third mode of operation of the water mist system, after "extinguish" and "flashover suppression." The term boundary protection as used in this study refers to a variety of means for stopping fire spread from compartment to compartment in the ship. If nozzles are functional in the compartment of fire origin, then application of even a moderate amount of mist will keep the compartment from reaching flashover. Consequently, the system is performing "boundary cooling" in that it is reducing temperatures on the fireside of the boundary. There is a reduced threat of conductive heat transfer through bulkheads causing ignition of combustibles in overlying or adjacent compartments. Nozzles may also be remotely activated on the non-fire side of a bulkhead to provide "boundary protection." The nozzles are not intended to spray solely onto the bulkhead, although where there are no obstructions direct spray will to a certain extent cool a hot bulkhead. The possibility of obstructions shielding portions of the bulkhead surface from water spray is quite high however, so a spray aimed at the surface would be no guarantee that ignition will not occur. By activating nozzles in the compartment prior to the occurrence of ignition as a preventive measure, ignition will be less likely to occur. If it does occur, there will be a limited amount of dry fuel available and fire growth will be slow and limited. The risk of fire spread to a tertiary compartment becomes very low.

The Phase I fire testing demonstrated that flashover suppression was achievable with small quantities of water mist. The test program did not, however, test the limits of performance of the system with different compartment sizes, or over a full-range of fuel densities. It was therefore premature to propose a ship-wide design based on that minimum level of water mist distribution. For the Phase II design the approach taken was to provide a water mist system designed for fire suppression or extinguishment with nozzles distributed over the overhead of a compartment in a manner similar to standard sprinklers. Design criteria for water mist fire protection systems of this type were taken from the commercial shipping domain. International Maritime Organization (IMO) test protocols for water mist systems for non-machinery spaces on passenger ships have been developed [4] and have resulted in the widespread installation of water mist systems as "equivalent to sprinklers" on commercial ships. A number of manufacturers of water mist system hardware have tested their systems to those protocols, so that proven design rules exist for layout of nozzles and determination of total water demand.

The IMO test protocols were developed to confirm that water mist systems could be installed as "equivalent to sprinklers" on ships. To "pass," a water mist system must meet the performance criteria of the test. It is worth noting that the standard marine sprinkler tested to the

water mist protocols did not perform as well as the successful water mist systems. Traditionally, sprinkler system design criteria are accepted without question as to whether they can actually provide adequate protection. The performance of water mist systems, on the other hand, has been confirmed as superior to sprinklers through actual full-scale fire testing [5, 6 and 7].

The water flow requirement for an IMO tested water mist system is much less than for a marine sprinkler system. A water mist system laid out to IMO-recognized design criteria is expected to provide a reasonably high probability of extinguishing Class A fires in small compartments [4]. It will certainly provide the minimum benefit of flashover suppression against the most severe fires. HP water mist systems have been proven not only to provide weight and space advantages over standard sprinklers, but also to be cost-competitive with standard marine sprinklers on passenger ships. For this study, the weight, space and cost savings afforded by water mist provide "capital" which can be applied to the design of an innovative distribution system architecture.

The designs examined in this report use the SHADWELL as a model for testing concepts. Although the concepts are suitable for installation and trial on the SHADWELL, they are intended to be generalized to application on new Navy ships. Two types of water mist system technology were examined – low pressure (LP) and high-pressure (HP) systems. Low-pressure water mist systems typically operate in the under-12-bar range (< 175-psig); HP systems operate in the 70 bar range (1000-psig). Nozzle layouts for both types of systems were imposed on the forward test areas on Main and Second Decks, Frames 15 to 29 of the SHADWELL. The LP nozzle layout required 40 percent more nozzles and approximately 100 percent greater water demand than the HP system. In this regard, the LP system had few advantages over a conventional marine sprinkler system. The Year 1 fire test program also showed that the HP water mist nozzles performed better than the LP nozzles, i.e., were more effective at reducing compartment temperatures and suppressing the fire [1]. The HP system permitted use of smaller diameter piping with benefits of greater freedom in design of the distribution system. Based on these considerations, the development of an architecture for an innovative, survivable distribution system presented in this report focused on the HP system only. The development work describing the LP system option is presented in Appendix A.

The water mist system design work is described in two parts. Section 2 of the report applies conventional IMO spacing rules to the water mist system design, which corresponds to the "extinguishment objective." It also explains the evolution and proposed advantages of the Sectional Loop architecture. In Section 3 the Sectional Loop HP water mist system design is modified for the "flashover suppression objective." The placement and number of nozzles and water mist control valves is changed from Section 2, but the Sectional Loop design of the distribution system remains the same as in Section 2.

Section 4 discusses issues relating to the cost impact of using a HP water mist system as a general fire protection system on a Navy ship compared to a system supplied from a traditional fire main. Section 5 concludes the report with discussion on the adaptation of the innovative system design as a test platform on board the SHADWELL.

## 2.0 WATER MIST SYSTEM DESIGN TO CONVENTIONAL MARINE (IMO) SPACING RULES

In this section, a nozzle layout is presented for a HP water mist system based on the spacing rules for commercially available water mist equipment. The commercial HP system meets the fire hazard control objectives established by the IMO fire test protocols [4]. These objectives exceed the "flashover suppression/boundary cooling" objectives examined in Phase I fire testing [1].

For the work reported in this Section, the nozzles are distributed over the overhead of a compartment in a manner similar to a commercial water mist system for passenger ships, which is intended to provide for extinguishment. Flashover suppression could be achieved with fewer, more widely spaced nozzles.

### 2.1 Nozzle Layouts

Layouts for HP nozzles were prepared for the forward test areas on Main and Second Decks, Frames 15 to 29 of the SHADWELL. The HP system involves nozzle pressures between 65 and 80 bar (943 and 1,160-psig). Spacing rules for the HP nozzles are presented in Table 1. The commercial HP system meets the fire hazard management objectives established by the IMO fire test protocols for "accommodation, public spaces and service areas" on civilian ships [4]. The IMO terminology of "Accommodation spaces, Corridors, Public spaces and Service areas" correspond in Navy terminology to "Small spaces," "Passageways," "Large spaces" and "Storage Areas," respectively.

This study examines the benefits of extending fixed fire suppression systems to protect all areas in the ship. Areas such as berthing and mess areas, small spaces, passageways, large spaces and most storage spaces typically involve Class-A combustibles. In the commercial marine systems intended for Class A fire hazards, the nozzles are thermally activated, i.e., they are closed until exposed to heat from a fire. Fire in Class-A combustibles grows out from a point of origin: nozzles closest to the fire sense more heat and open before more remote nozzles. The water demand grows as the number of activated-nozzles increases, but in principle, no more nozzles open than necessary to control the fire. In contrast, Class B fuels in machinery spaces might spill over the entire deck area of the compartment, such that it is necessary to operate all nozzles in the compartment. Machinery spaces are therefore protected with open nozzles that operate in the manner of a deluge system. Water mist deluge systems for machinery spaces onboard Navy ships have been fully addressed in previous studies [8].

Table 1. Spacing and Flow Criteria for HP Water Mist System Nozzles for Marine Applications

| IMO Compartment Dimensions | Cabins < 16 $m^2$ | Rooms > 16 $m^2$ | Rooms > 16 $m^2$ | Width < 1.5 m | | |
|---|---|---|---|---|---|---|
| Navy Terminology | Small Compartments | Large Compartments | Large Compartments, 2 deck Height | Passageways | Storage Space | Machinery Spaces |
| FM or UL, Land based Terminology | Light Hazard | Light Hazard | Light Hazard | Light Hazard | Ordinary Group 2 | Machinery Spaces |
| Maximum Deck Heights | 2.5-m | 2.5-m | 5.0-m | 2.5-m | 2.5-m | 2.5-m |
| Nozzle Designation [(1)] | 1B-1MB-6MB | 1B-1MB-6MB | 1B-1MC-6MC | 1B-1MC-6MC | 1B-1MC-6MC | 4S-1MC-8MB |
| Glass Bulb, (GB) or Open (O) | GB | GB | GB | GB | GB | O |
| K-factor, L/min/bar $^{1/2}$ | 1.35 | 1.35 | 2.50 | 2.50 | 2.50 | 1.90 |
| Discharge at P = 70-bar, L/min | 11.3 | 11.3 | 20.9 | 20.9 | 20.9 | 15.9 |
| Max. distance to bulkhead, m | 2.85 | 1.80 | 1.90 | 1.90 | 1.49 | 2.50 |
| Max. spacing, m | One nozzle/room | 3.50 | 3.75 | 3.75 | 2.65 | 2.50 |
| Max. Coverage area, $m^2$ | 16.0 $m^2$ | 12.3 | 14.1 | 14.1 | 7.0 | 6.3 |
| Nominal Density; L/min/$m^2$ | 0.7 | 0.9 | 1.5 | 1.5 | 3.0 | 1.9 |

**1. Nozzle Designation Code: 1B-1MB-6MB or 4S-1MC-8MB**

6MB or 8MB — 6 or 8 Mist orifices surrounding the center jet, B = 0.7-mm diameter, C = 1.0-mm diameter
1MB or 1MC — 1 Mist orifice on center axis, B = 0.7-mm diameter; C = 1.0-mm diameter
1B or 4S — 1 = 120 degree cone angle, thermally activated; 4 = 90 degree cone, open nozzle; B = brass; S = stainless steel

Nozzle layouts for the forward test areas on Main and Second Decks, Frames 15 to 29 of the SHADWELL, are shown in Figures 1a and 1b. Nozzles are shown in every compartment, as would be required by IMO design rules. (It is recognized that some of the actual outboard compartments on the SHADWELL will not be equipped with nozzles, i.e., outside the test area.) The maximum permitted distances between nozzles and from bulkheads are indicated. The legend in the Figures identifies typical nozzle designations and spacing rules for different types of compartments. For example, the designation "1B 1MB 6MB @ 2.85/2.85 Small Compartments, K =1.35" denotes a nozzle that is suitable for small compartments (up to 16-$m^2$ deck area), can be spaced up to 2.85-m apart and 2.85-m from a bulkhead, and has a K factor of 1.35 ($L/min/bar^{1/2}$). These criteria are taken from the data sheets for commercially available water mist nozzles and are based on the system configuration that meets the IMO test "pass" criteria.

In this evaluation, both closed-thermally-activated and open nozzles were considered for use in spaces involving Class A combustibles. Whether nozzles are normally open or normally closed is not critical to the development of the rupture control logic for the distribution system. There are potential benefits for using open rather than thermally activated nozzles in the Class A fire hazard areas. Figures 2a and 2b show tubing and valves arranged to control groups of nozzles in each compartment. (Nozzles shown in outboard compartments in Figures 1a and 1b are omitted from spaces reserved for instrumentation in Figures 2a and 2b). With the addition of "water mist control valves" (WMCV's in Figures 2a and 2b) on each branch pipe supplying a group of nozzles, it will be possible to proactively operate nozzles in different compartments, without waiting for the space to become hot enough to thermally release them. Thus, the nozzles can be activated in compartments adjacent to a fire compartment, to prevent fire from spreading, i.e., for "boundary protection." Open nozzle systems require input from a supplementary detection system which makes the system less "reflexive" than a system using individually thermally activated nozzles.

Table 2 indicates the number of nozzles counted in Figures 1a and 1b in each section between Frame 29 and Frame 15 of Main and Second decks on the SHADWELL. Due to differences in compartmentation, the total on main deck was 51 nozzles; the total on 2nd deck was 53 nozzles. There were more nozzles between Frames 29 and 22 than between Frames 22 and 15, because of the narrowing of the ship. If the ship beam were constant there would be roughly the same number of nozzles in both sections. For the purpose of generalizing the design process, it was assumed that a "section" typically requires 30 nozzles. Some sections with more subdivisions could require more, while some could require fewer than 30 nozzles. This nozzle count is considered to be representative for a water mist suppression system on a generic Navy ship.

To further generalize the remainder of this analysis, it is assumed that a generic ship will be divided into four fire zones, each approximately 30.5-m (100-feet) long. The areas between watertight bulkheads (for example, between Frames 15 to 22, and Frames 22 to 29 on the SHADWELL) are referred to as "Sections." A fire zone would include four such sections on each deck level.

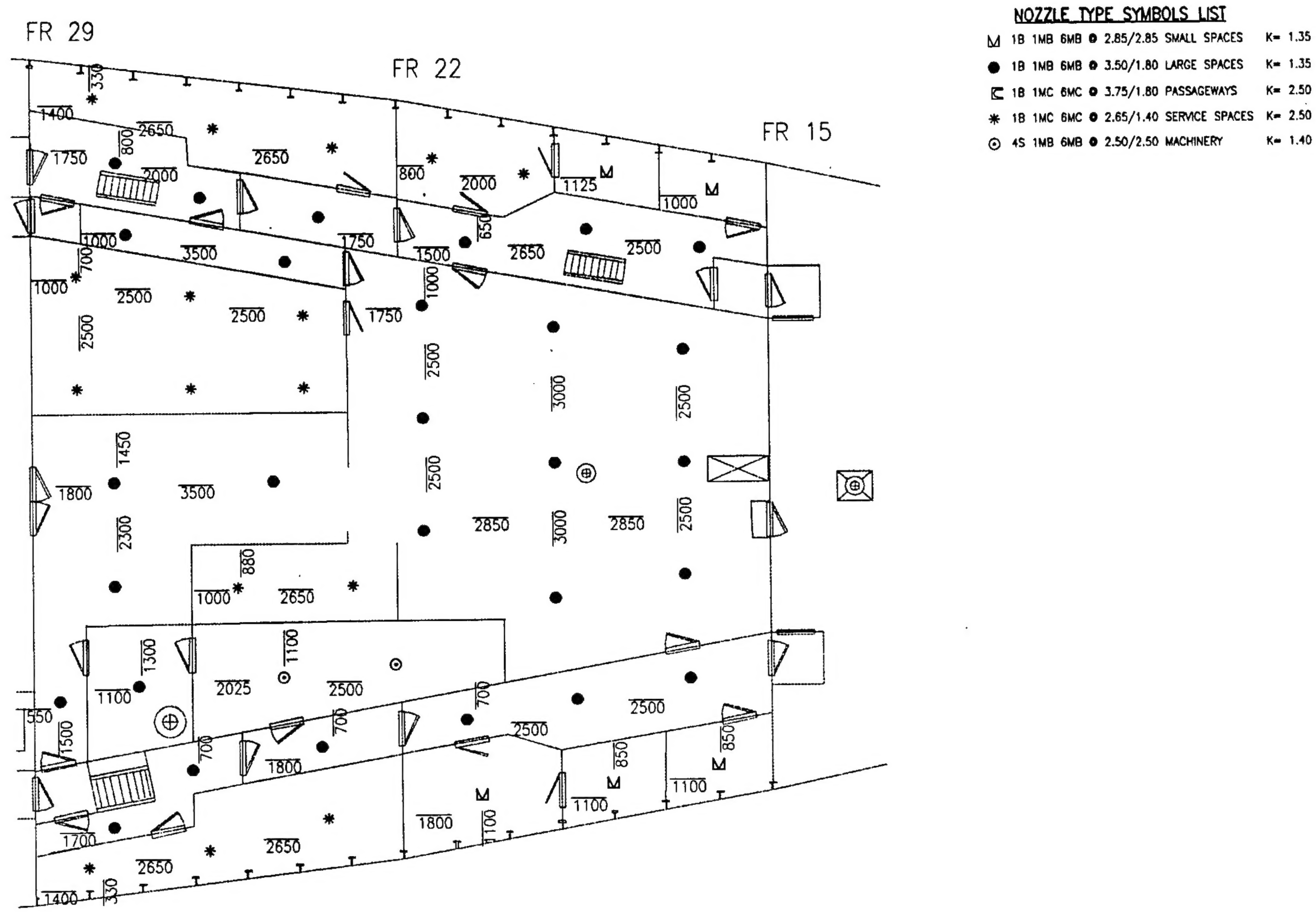



**Figure 1a – HP system nozzle locations and spacing dimensions, Main Deck of ex-USS *Shadwell*, between Frames 15 and 29, based on IMO design criteria**

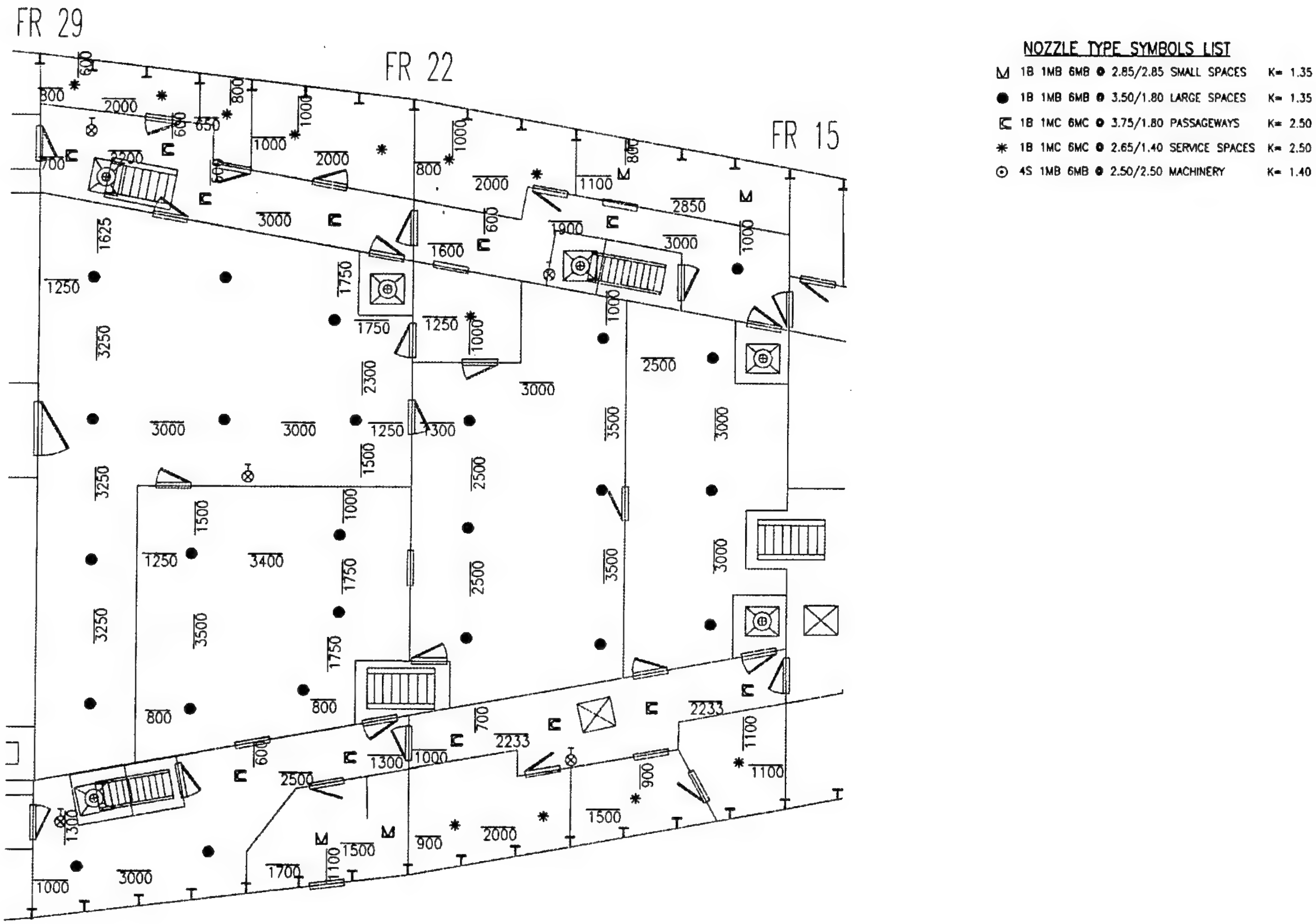



**Figure 1b – HP system nozzle locations and spacing dimensions, Second Deck of ex-USS *Shadwell*, between Frames 15 and 29 based on IMO design criteria**

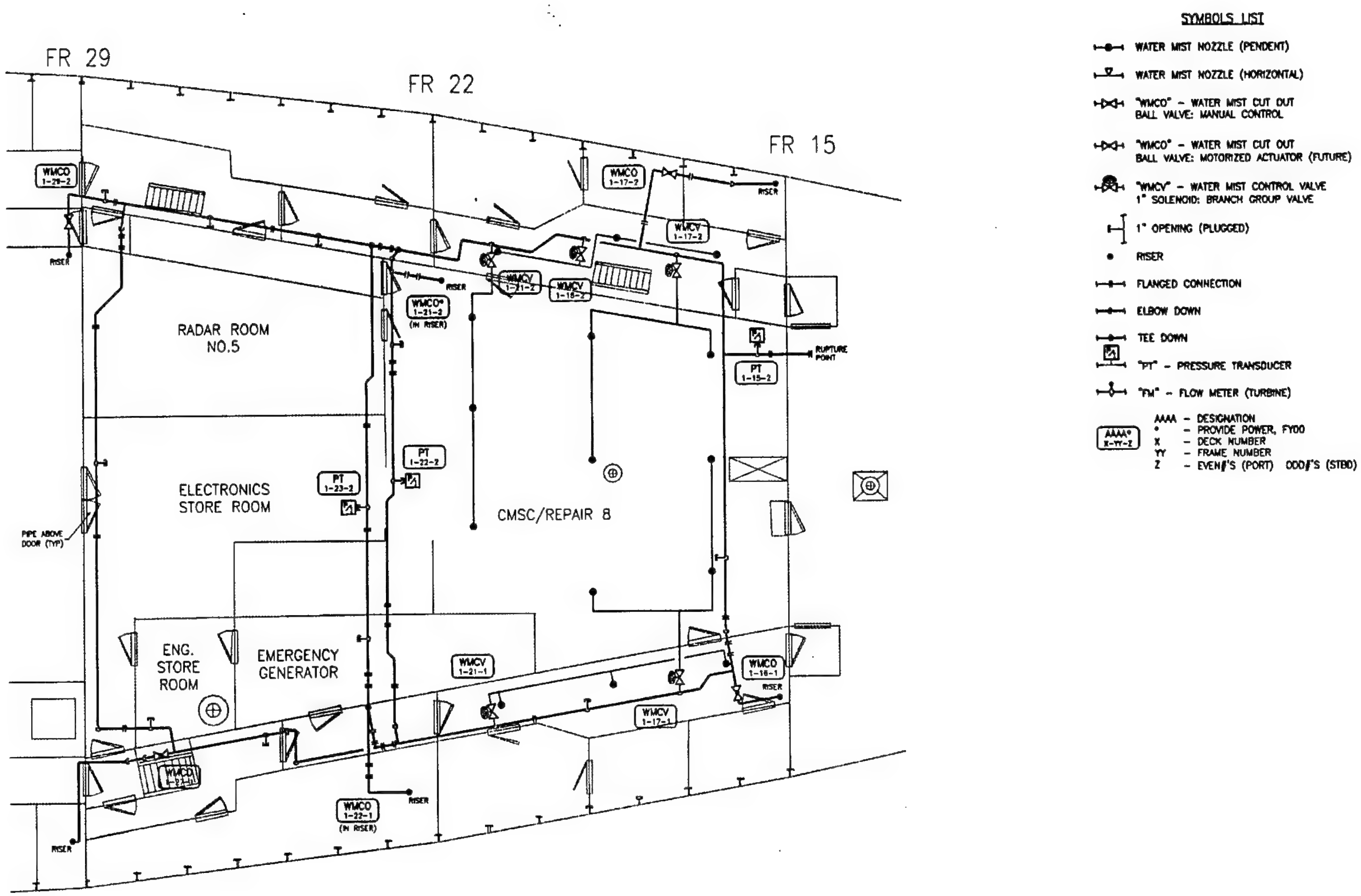



**Figure 2a - HP system nozzle locations and branch group piping, Main Deck of ex-USS *Shadwell* between Frames 15 and 29**

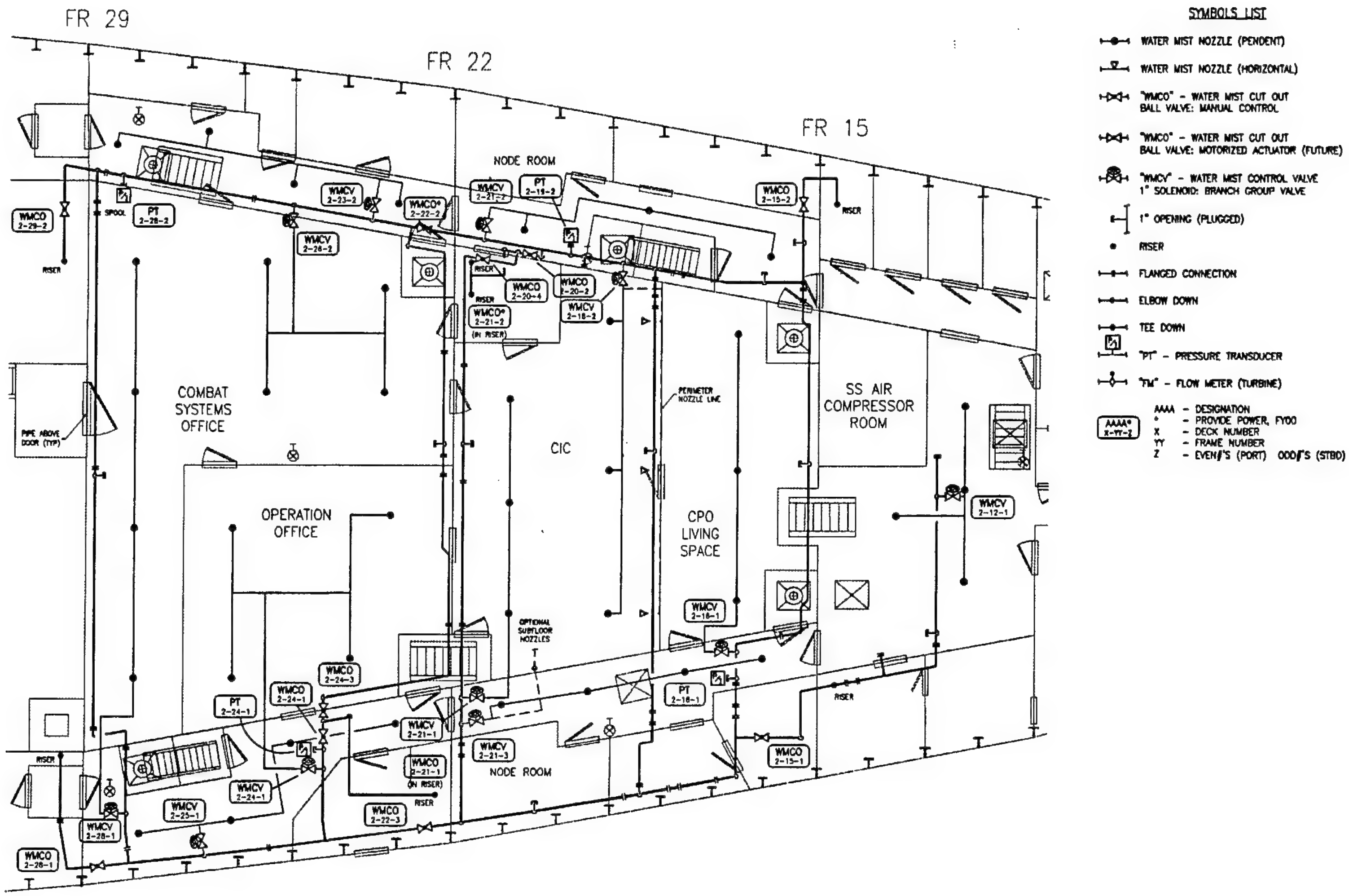



Figure 2b – HP system nozzle locations and branch group piping, Second Deck of SHADWELL, between Frames 15 and 29

Table 2. Summary of Nozzle Counts for a HP Water Mist System Laid Out to IMO Spacing Criteria on the SHADWELL (Ref. Figures 1a and 1b)

| AREA | Nozzle Count<br>Frames 29 – 22<br>Section I | Nozzle Count<br>Frames 22 – 15<br>Section II | Frames 29 - 15<br>Total for Two Sections per Deck |
|---|---|---|---|
| Main Deck | 29 | 22 | 51 |
| 2nd Deck | 28 | 25 | 53 |
| Generalized area, any deck full beam width of ship | 30 | 30 | 60 |

## 2.2 Water Flow Demands

Nozzles shown in Figures 1a and 1b are shown connected to water supply pipes in logical groupings in Figures 2a and 2b. For cases where there are a number of nozzles in a compartment, they are grouped either along the frame line, or along passageways between watertight bulkheads. It is intended that groups of nozzles be activated across the width of a ship (e.g., at a frame line), within the compartments, or along passageways between watertight bulkheads. All nozzles supplied by a single branch pipe comprise a "branch group." As shown in Figures 2a and 2b, a WMCV controls flow of water to each branch group. There are typically three or four nozzles per branch group. Larger compartments may contain two or three branch groups.

Options for how and where branch lines may be connected to the supply mains will be discussed later in this report. The layout shown in Figures 2a and 2b was used for estimating water flow demands. Table 3 compiles the nozzle count and estimated water flow demands for a HP system on the SHADWELL. The minimum water flow demands for various operating areas were calculated on the basis of the numbers of branch groups discharging water. Using the largest K factor nozzle in Table 1 ($K = 2.5$ l/min/bar$^{1/2}$)-(the "1B 1MC 6MC" nozzle) and a nominal operating pressure of 70 bar (1015 psig), design flow rates were calculated based on a 4-nozzle branch group.

Table 3 shows the expected nominal discharge per nozzle, per group of 4 nozzles, and for different numbers of branch groups. For peacetime conditions, it is reasonable to assume that a fire will be confined to the compartment of origin and controlled by the mist system [1]. The largest compartment on the SHADWELL contains 10 nozzles, which would be supplied by three branch groups. The demand for a typically large compartment is a reasonable value to use for peacetime conditions (Design Q1). However, the capacity of the pumping system should not be limited to a minimal peacetime demand.

More challenging fire conditions are encountered during wartime damage scenarios. Table 3 shows calculated water demands for a successively greater number of operating branch groups. Not only could three branch groups be required to flow if all nozzles in the largest compartment were operating, but also a fourth group in the adjoining passageway (Q2) could be

needed. It might be necessary to operate water mist nozzles on more than one deck forward and aft of the damaged section. Two branch groups on each of two decks, forward and aft of a fire damaged section, would demand a total of 8 branch groups (Q3). If four branch groups were activated at the same time in the overlying compartment to prevent vertical fire spread, 16 branch groups would be required (Q4).

Table 3. Summary of Design Water Flow Demands for a HP Water Mist System in Small and Large Berthing Compartments, Storage, Service, and Machinery Spaces on Navy Ships

| Fire Zone = 30.5 m (100 ft) | Qty | Design Flow L/min | Design Flow Gal/min | Design Condition |
|---|---|---|---|---|
| Flow rate per nozzle at 70 bar nozzle pressure [1] | 1 | 21 | 5.5 | Using largest K factor nozzle: K = 2.5 L/min/bar$^{1/2}$. Some lower K factor nozzles will be used. |
| # of Nozzles per Section | 30 | 630 | 166 | Nominal, Per deck level |
| Total flow from 1 Branch Group | 1 | 84 | 22 | Standardized to 4 nozzles per Branch Group |
| Total flow from 3 Branch Groups | 3 | 252 | 67 | Design Q1: Largest compartment, one deck |
| Total flow from 4 Branch Groups | 4 | 336 | 89 | Design Q2: Large compartment + passageway |
| Total flow from 8 Branch Groups | 8 | 672 | 178 | Design Q3: Fore and aft, two decks |
| Total flow from 16 Branch Groups | 16 | 1,344 | 355 | Design Q4: Wartime damage scenario, boundary protection – fore, aft, on two decks + above fire |
| Machinery Space (Nominal) | 1 | 380 | 100 | Design Q5: Nominal allowance for machinery space deluge protection. |

*1 The nominal nozzle operating pressure for design is 70-bar (1015-psig). The actual nozzle pressures will vary between approximately 80 and 65-bar (1,160 and 943-psig) depending on elevation and position in the system.*

For a peacetime scenario, a reasonable design water flow demand would include the machinery space demand (Q5), plus 8 branch groups (Q3): a total demand of 1,050 L/min (278-GPM). For a wartime damage scenario, the design will be based on the possibility of sixteen branch groups operating [Q4 = 1,344 L/min (355 GPM)]. This corresponds to three branch groups per deck fore and aft of the damaged section, on two decks, plus four branch groups in the overhead of the compartment above the fire.

## 2.3 Pumping Strategy

There are several possible approaches for providing pumping capacity for the HP water mist system. All arrangements have benefits and disadvantages. Four options with their primary advantages or disadvantages are described in Table 4.

Table 4. Options for Providing Pumping Capacity for the HP Water Mist System

| Arrange-ment | Basic Pumping Strategy | Comments |
|---|---|---|
| A | One large pump unit supplying a distribution main and multiple risers, sized to meet the full design flow rate; no redundancy | Arrangement A has no redundancy and is not considered further. |
| B | Many small pumps distributed throughout the ship, each supplied locally with water from the firemain, with local filtration, recirculation or bypass line and control panel. | Numerous small pumps "in series" with the fire main incurs high cost for power supply, control, suction piping, filtration, and recirculation piping. It negates use of freshwater for water mist instead of seawater; its functionality after battle damage depends entirely on the functionality of the fire main. Not considered further. |
| C | Two pump units in parallel, one aft of midships, and one forward serving a common distribution header and multiple risers; each pump unit sized to meet full design flow, so that one unit is redundant | Provides for 100 percent redundancy at a reasonable cost for connections, power, and filtration. Can use fresh water. Pump units are adequately separated so that at least one should be functional at all times. |
| D | Four pump units in parallel, one for each Fire Zone (30.5-m (100-ft)) of ship; each pump unit sized for 1/3 of the full design flow, so that three units will meet full design flow with the largest unit out of service | Arrangement D provides for redundancy in a way that permits each pump unit to be smaller than arrangement C, such that redundancy can be achieved with three of the four pumps. (One out of all four pumps can fail.) |

Arrangement C provides for a minimum acceptable level of redundancy and the distribution system is completely independent of the fire main. It would be marginally less costly than Arrangement D but it does not provide for as much design flexibility for the water supply. Arrangement D, with one pump unit per fire zone, has significant advantages over the others in terms of design freedom. The remainder of this design is based on Arrangement D. Figure 3 shows the conceptual arrangement with four pump units, one per fire zone. Figure 3 illustrates a strategy for connecting all four pumps in parallel by means of a "ring main" at the pump deck level. Risers are spaced along the ring main as shown to supply looped piping on the decks above.

The 65 – 80-bar (943 – 1160-psig) operating pressures required of the HP water mist system cannot be achieved using centrifugal fire pumps. Piston-type positive displacement (PD) pumps are used. Until recently, PD pumps have not been used with fire protection systems because special design features are required to match the fixed volume output of the PD pump to a system of variable demand. Positive displacement pumps discharge a fixed volume of water with each stroke of the piston, whereas the discharge rate of a fire protection system may vary depending on how many nozzles are opened by the fire. When the system demand is less than the capacity of a single pump, the unused capacity must be recirculated. When the system demand exceeds the capacity of one pump, additional pump units must be brought on-line.

Positive displacement pumps are now widely used for HP water mist systems on commercial passenger ships. The basic pump unit consists of an assembly of small pumps and electric motors – sometimes with one motor driving two individual pumps. The discharge lines are coupled with "flow-bypass valves," also known as re-circulation or "pressure

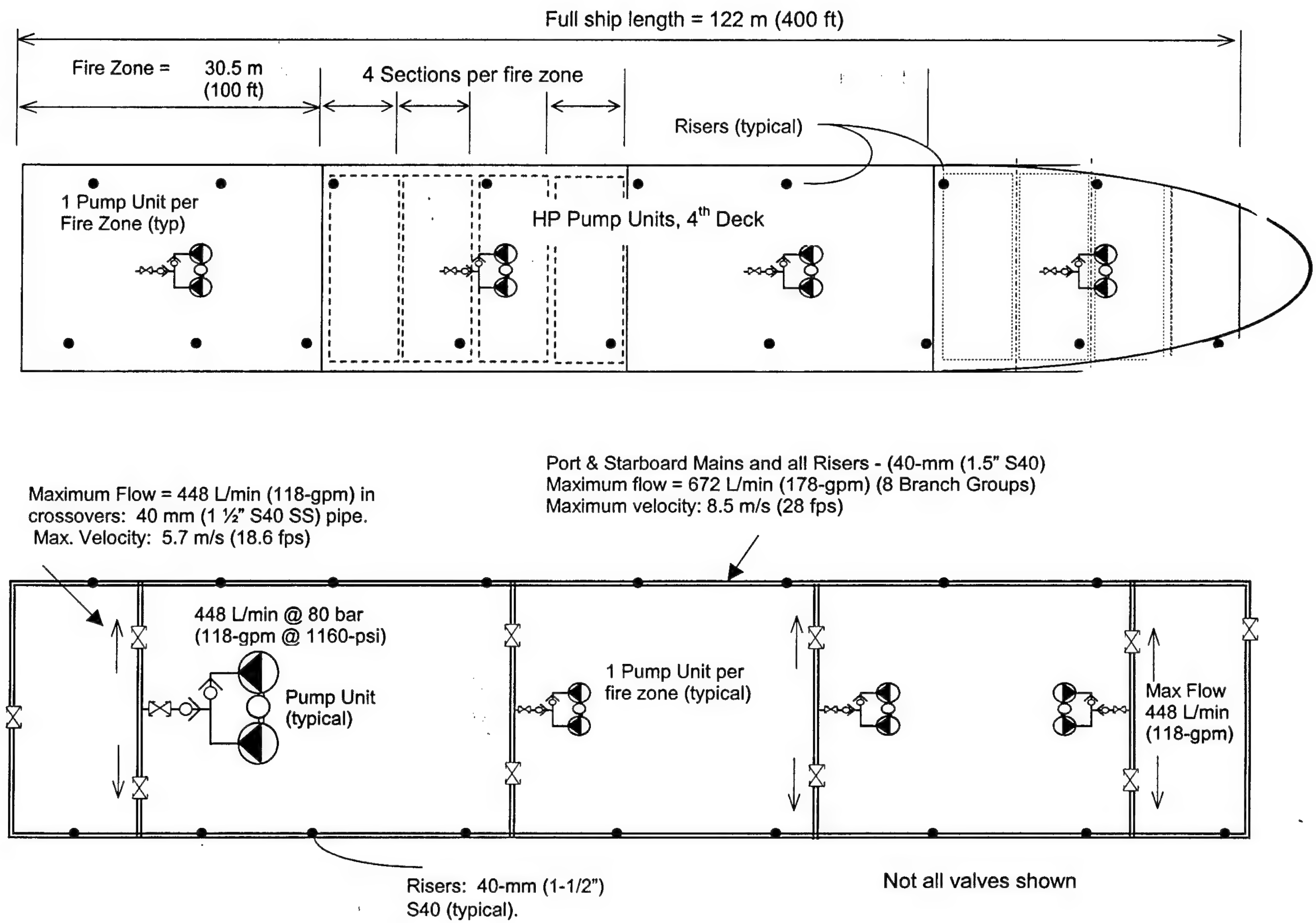



**Figure 3 - Conceptual layout of fire zones, fire sections and pump units for a HP water mist system, showing four pump units "in parallel" with a ring main on 4th Deck level**

unloader" valves. The unloader valves open at a set pressure to bypass unused flow. As the demand of a system increases due to opening of more nozzles, more pumps are started to keep up with the demand.

Figure 4a illustrates an arrangement of two PD pumps (Alpha and Beta) to meet different demand conditions. One motor is used to drive both pumps. The motor is sized (kW or BhP) to provide the output of a single pump at maximum pressure or the output of two pumps at one-half the single-pump pressure. A check-valve held closed by the HP from the Alpha pump prevents flow from the Beta pump from entering the system (it bypasses it to the suction line via the flow-bypass valve). As long as the system demand is less than or equal to the volumetric capacity of the Alpha pump, the system pressure remains "high." Thus, the first nozzles to operate at the early stage of a fire deliver water mist with maximum velocity and flow rate, thus increasing their initial effectiveness on small fires. If more nozzles open, the volumetric demand eventually exceeds the capacity of the first pump. The system pressure will drop to the setting of the Beta flow-unloader valve, allowing flow from that pump to enter the piping system. The volumetric output of both pumps is then supplied to the piping system, but at the lower pressure. The power (kW, brake horsepower) of the motor determines the maximum discharge pressure of the pump under either the maximum or one-half pressure condition.

For a large water mist system, several pump-pairs may be assembled in a skid. Figure 4b represents an assembly of pump-pairs connected in parallel to provide a continuous range of flow to a water mist system. The minimum demand for a system, for example one or two nozzles operating, can be met with one pump operating, with some of the total output being bypassed. As more nozzles open, the system pressure drops until it falls below the setting of the next flow-bypass valve. That valve then closes and flow from that pump goes into the distribution system instead of the re-circulation bypass. In this way, the pump unit self-adjusts to meet the varying demand of the water mist system. Other means of varying the output from a bank of positive displacement pumps are possible, such as adding adjustable frequency drivers to vary the speed of the pump. Nonetheless, the hydro-mechanical means using a combination of many small pumps and adjustable flow-bypass valves is fully serviceable over a wide range of flows. Distributing a number of small pumps rather than one big pump is also considered more survivable.

Figure 5 illustrates the recommended strategy of Arrangement D for meeting the wartime damage water flow demand of 1,344 L/min (355-gpm) for 16 branch groups. Each pump unit is capable of delivering up to 1/3 of the total demand (448 L/min (119-gpm)), so that one pump unit is redundant under the maximum load. Figure 3 shows a possible arrangement for connecting all four-pump units in parallel.

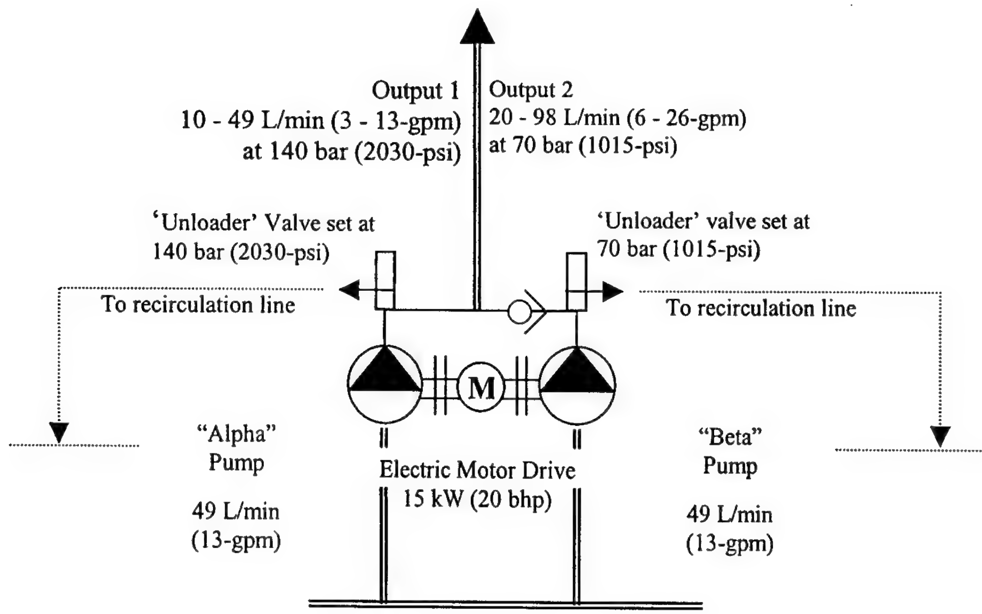



**Figure 4a – Diagram of a commercial HP water mist positive displacement pump pair consisting of two positive-displacement pumps with a single electric motor driver**

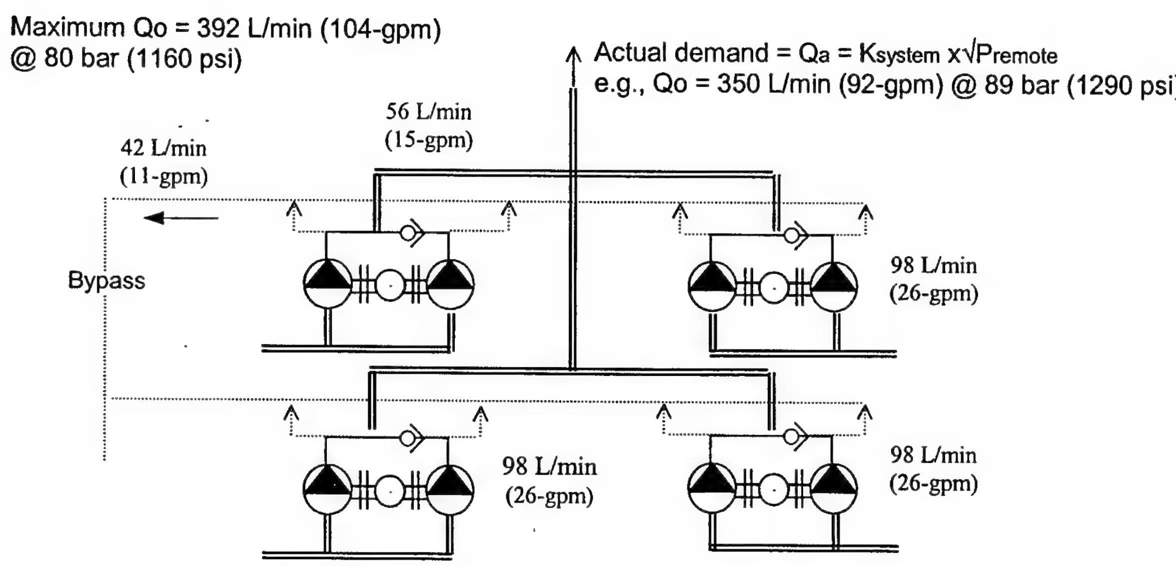



**Figure 4b – Diagram of an assembly of pump-pairs connected in parallel to provide a range of flows to a water mist system**

**Number of Pump Units Required for Design Demand**

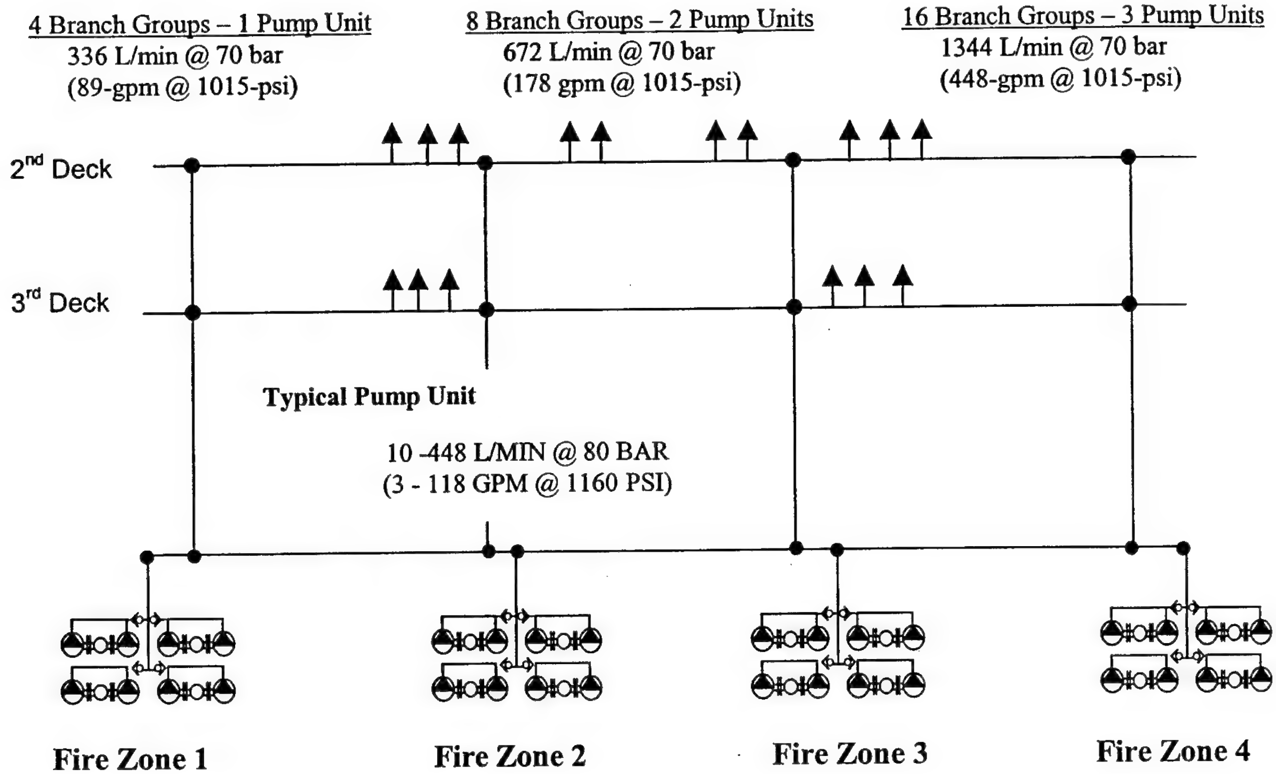



**Figure 5 – Recommended HP pump strategy – one pump unit per fire zone**

## 2.4 Distribution System Options

The objective of this analysis is to develop a distribution system for the water mist for Navy ships that will have a high degree of survivability under battle damage conditions. The term "architecture" refers to the overall design of the piping system: the degree of redundancy in sources of water (pumps), the number of routes available for water to reach any portion of the distribution system, the degree of separation between redundant components, and the arrangement of control valves and control sensors. Pressure sensors can be used to allow the system to self-diagnose that a rupture condition exists; automated valves can be used to automatically shut off flow to damaged portions of the distribution main. Other factors that are needed to ensure system functionality, but which are not discussed here, include the integrity of the power supply to pumps and valves, and communications circuits and logic systems to achieve control. The following discussion relates to the architecture of the pumping, piping and valve arrangements, and assumes that the problem of achieving equal survivability of power and communication circuits will be addressed separately.

Figure 3 (previously referenced) illustrates an arrangement of fire zones for a generalized Navy ship. The generic ship is divided into four fire zones approximately 30.5 m (100 ft) long, defined by the water and smoke-tight bulkheads. Within each fire zone are "sections," which also are defined by watertight bulkheads. An architecture to maximize survivability must consider strategies for determining the number of pumps and valves required to meet flow requirements, and provide redundancy. Section 2.3, Pumping Strategies, concluded that a four-pump unit design (Arrangement D in Table 4 - one pump unit per Fire Zone, will be used for this design. The pump units are sized to provide one-third of the maximum flow demand, so that one pump unit could fail and the demand could still be met by the remaining three pump units.

The design for "survivability" of the piping system from battle damage involves many factors other than the basic arrangement of pipe runs and valves. It also involves details of the location, mounting and armoring of vital risers and cross-mains, and of hardened valves and control components. This study concentrates on the basic layout of the piping system including the valving logic, for the purpose of maximizing the area of still-functional water mist piping after a damage event. The term "survivability" as used in this report relates to the physical area in which the system is still functional, i.e., able to deliver water mist at the appropriate pressure and flow rate.

Several conceptual piping arrangements for supplying the HP water mist nozzles between Frames 15 and 29 on the Main and Second deck of the SHADWELL were prepared. The layouts are conceptual. They provide a visual means for evaluating the survivability associated with different main and valve arrangements. Actual piping routes on the SHADWELL will be selected in cooperation with field personnel, after the conceptual design is complete.

Assumptions underlying the distribution system layouts are as follows:

1) Nozzles will be either normally closed, thermally activated or open, deluge types. In both cases, an electrically controlled valve is provided on each branch line so that flow to nozzles can be shut-off remotely. It is intended that a hybrid nozzle that can be both locally thermally activated, and remotely triggered, will be investigated at a future time.

2) Nozzle groups are defined by the compartment boundaries. Typically, there are 3 or 4 nozzles per branch connection supplied by one connection to the water mist main. Nozzles in large spaces are grouped along frame lines so that successive branch lines of nozzles can be remotely activated one-at-a-time across the beam of the ship for boundary protection purposes. That is, fire will not be able to spread along the length of the ship without encountering a starboard-to-port water mist curtain. Water flow demands are calculated based on a nominal number of 4 nozzles per branch group.

3) The piping is charged with water at all times (wet pipe system) up to water mist control valves on individual lines of nozzles. Water supply will be from a fresh-water source. The pump units themselves are not affected by the damage event.

4) Main control valves are intended to be "smart valves" that are equipped with pressure sensors and a programmable motorized actuator. They are capable of self-diagnosing that a rupture condition exists, and determining which valves should close to isolate the rupture. After the rupture is isolated, the remainder of the intact system returns to full operational capability. The water mist system smart valves are similar in principle to the smart valves described in reference [3] for the fire main.

Three basic layouts were investigated: "center main," "dual main" and "sectional loop." Figures 6a to 8d illustrate the three architectures.

Figures 6a to 6c show the center main design. It has a single main running along the centerline of the ship on each deck, with sectional control valves at zone boundaries and all riser connections. Risers are spaced along the ship to bring water from lower decks where the pumps are located, to each deck level. Branch groups are connected to the main with a branch group control valve. If the pipe is ruptured between two risers on one deck, valves on the mains close to isolate that length of pipe. Water can still flow to the intact portions of the main on that deck through the risers from lower decks. The main size must be large enough to take the combined flow of all operating branch groups in the area serviced.

Figures 7a to 7c illustrate the "Dual Main" concept. It has a main in both starboard and port outboard areas. Vertical risers spaced at intervals along the length of the ship supplying the mains on each side. Branch group lines are connected to either the port or starboard main, with a branch group control valve on each line. Valves are placed at intervals along the two mains so that a damaged portion can be isolated. Any undamaged branch lines within a compartment that happen to be fed from the undamaged side of the ship will still be functional. The dual main concept can be combined with crossover mains and valves to create a series of "offset loops." The offset loop divides each loop between two decks, such that one half of the loop covers one side of the ship at one deck level, while the other half of the loop provides water to the opposite side of the ship on the deck above. Offset loop crossover mains are not shown in Figure 7a, but are indicated in Figures 7b and 7c. Installing crossover mains approximately at fire zone boundaries would convert the "dual main" to "offset loop." The offset loop architecture is an intermediate step toward the sectional loop design.

The "sectional loop" concept is shown in schematic form in Figure 8a, and as applied to the SHADWELL in Figures 8b to 8d. Like the dual-main arrangement, there are mains along port and starboard outboard areas, and vertical risers spaced at intervals along the length of the ship. The sectional loop arrangement has a riser for each loop and may connect to the loop at any point. In other words, although risers alternate between port and starboard sides along the

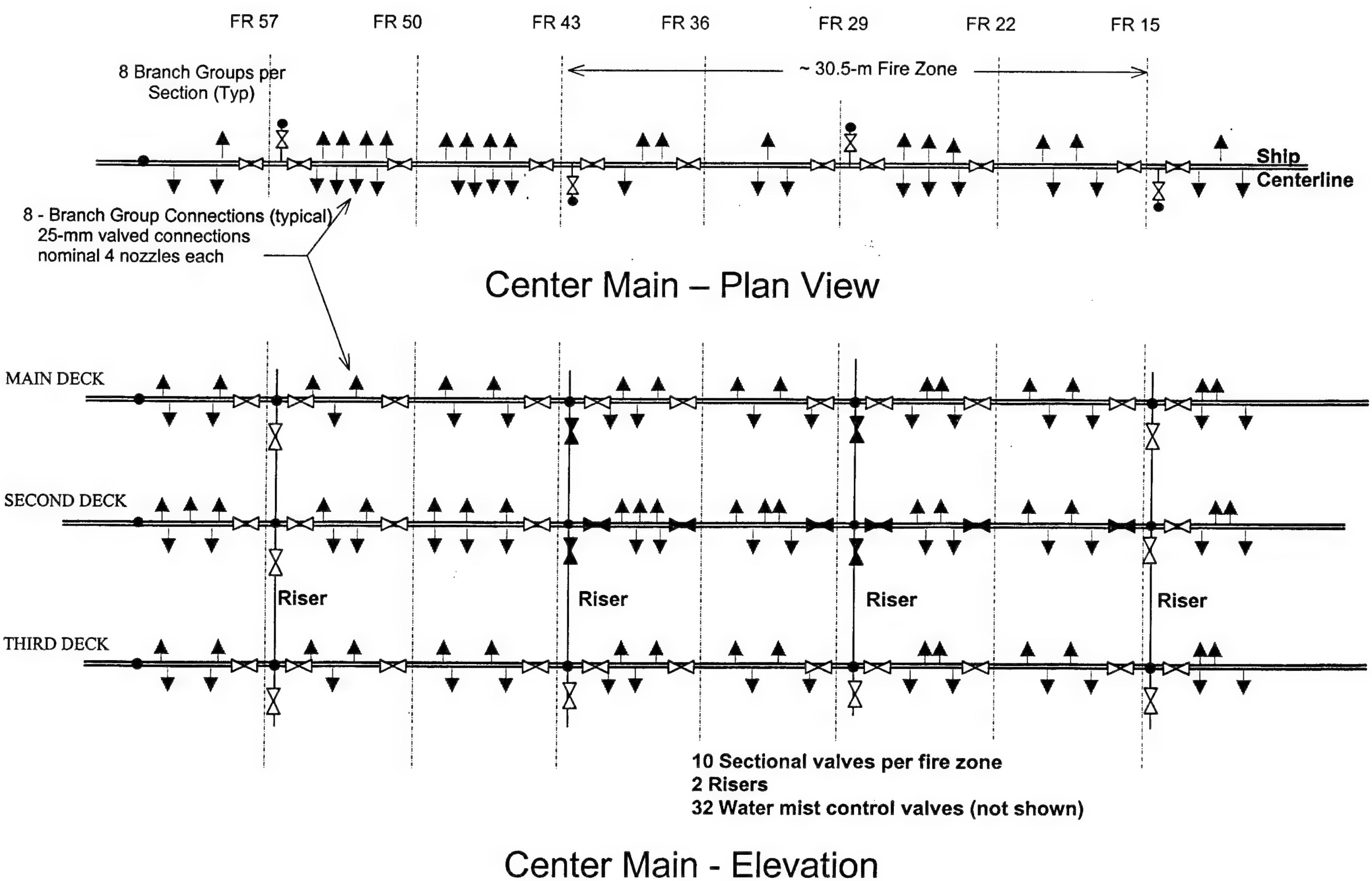



Figure 6a – Piping schematic showing generalized Center Main architecture, plan, and elevation views

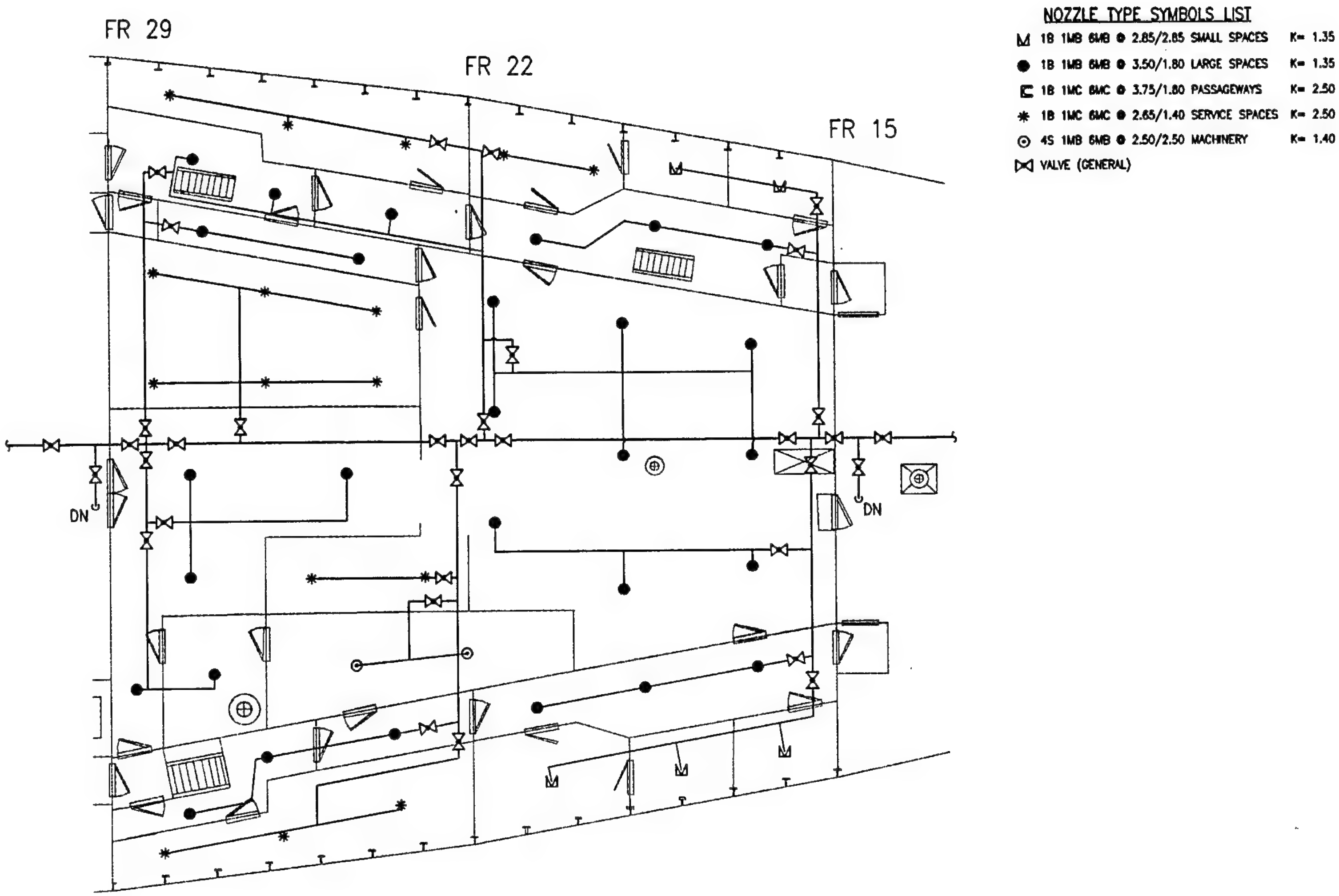



**Figure 6b – Center Main piping layout, Main Deck, ex-USS *Shadwell***

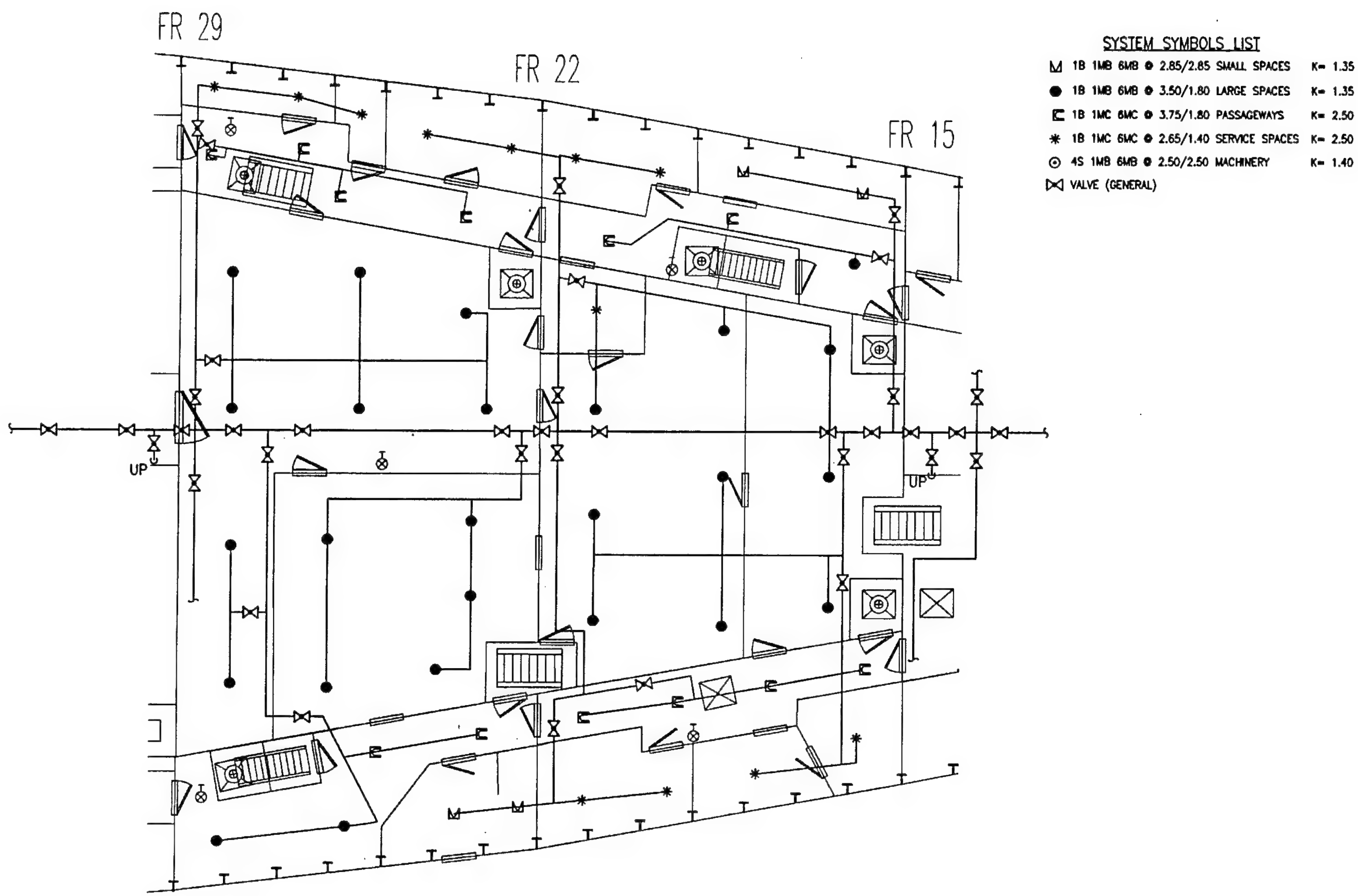
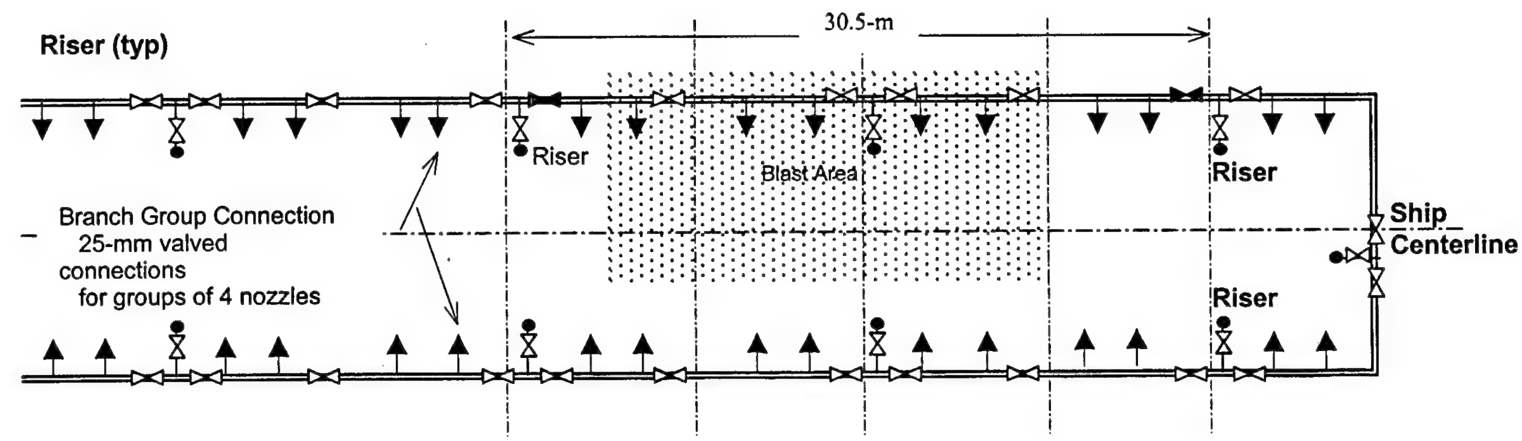
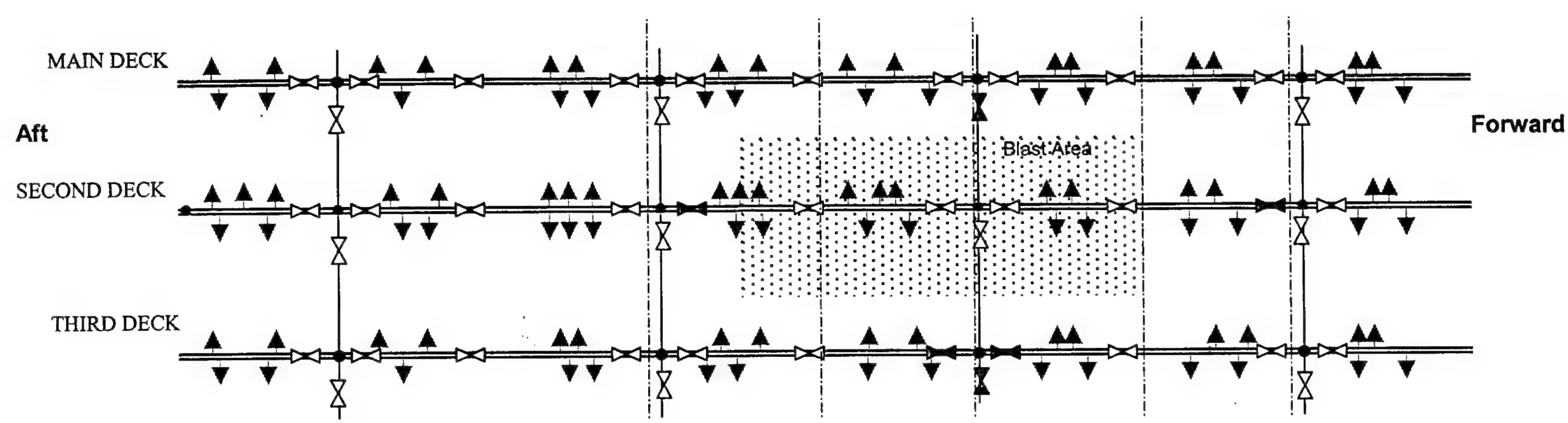



Figure 6c – Center Main piping layout, Second Deck, ex-USS *Shadwell*




**Dual Main Plan View – Any Deck**




**Dual Main - Elevation View**

**Figure 7a – Piping schematic showing generalized dual main architecture**

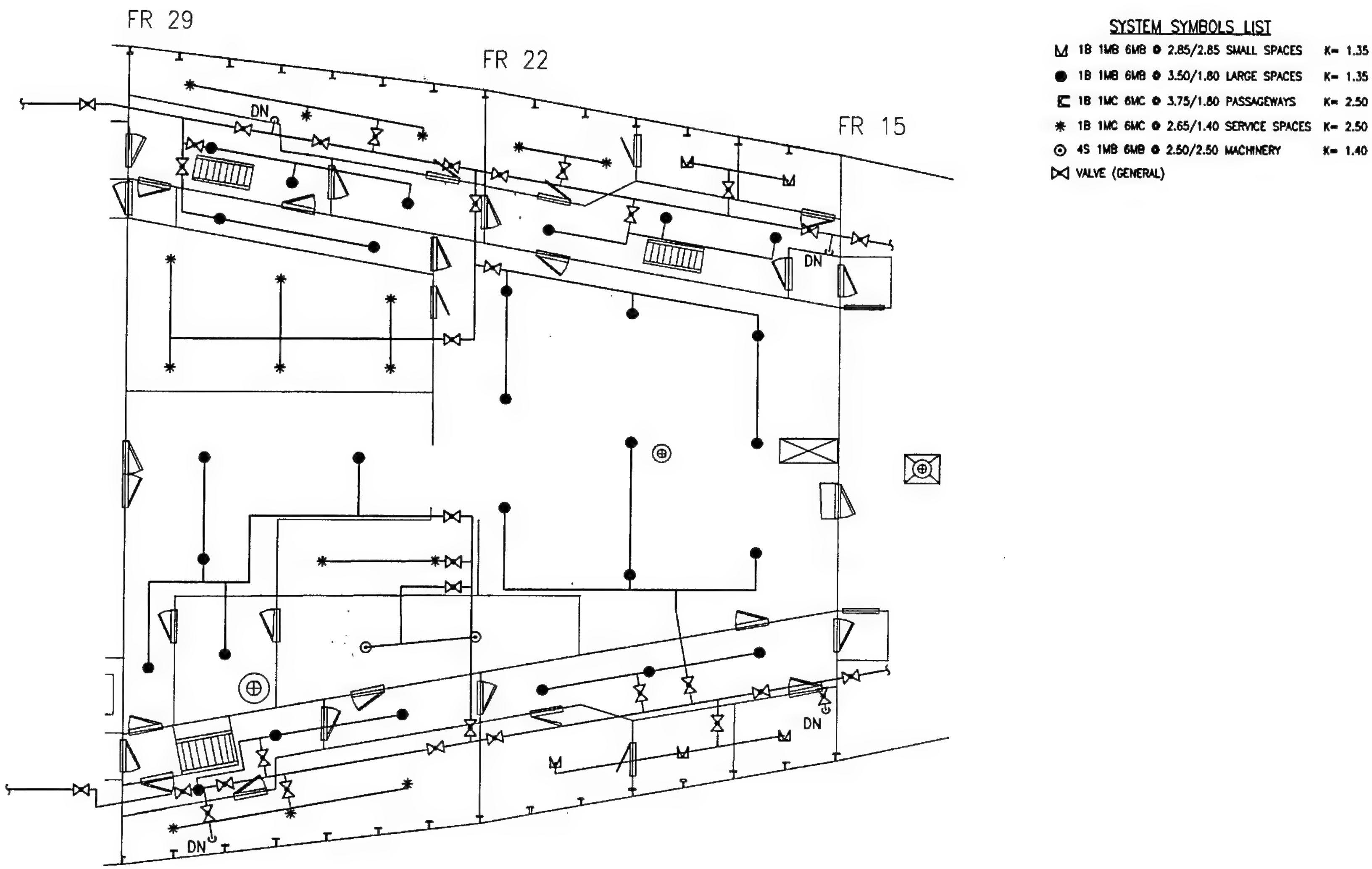



Figure 7b – Dual Main piping layout, with “offset loop” crossover connections, Main Deck, ex-USS Shadwell

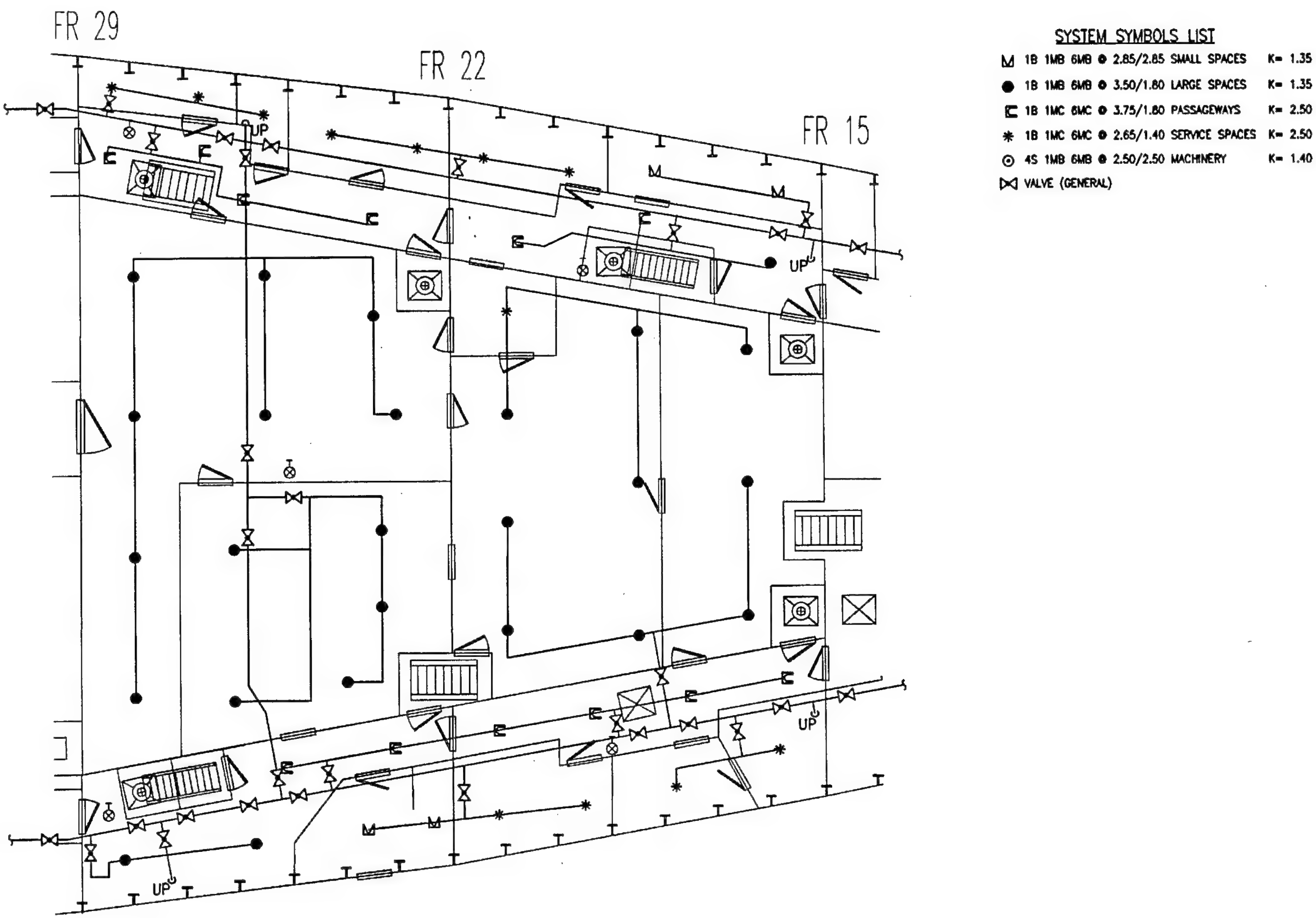



Figure 7c – Dual Main piping layout, with "offset loop" crossover connections, Second Deck, ex-USS *Shadwell*

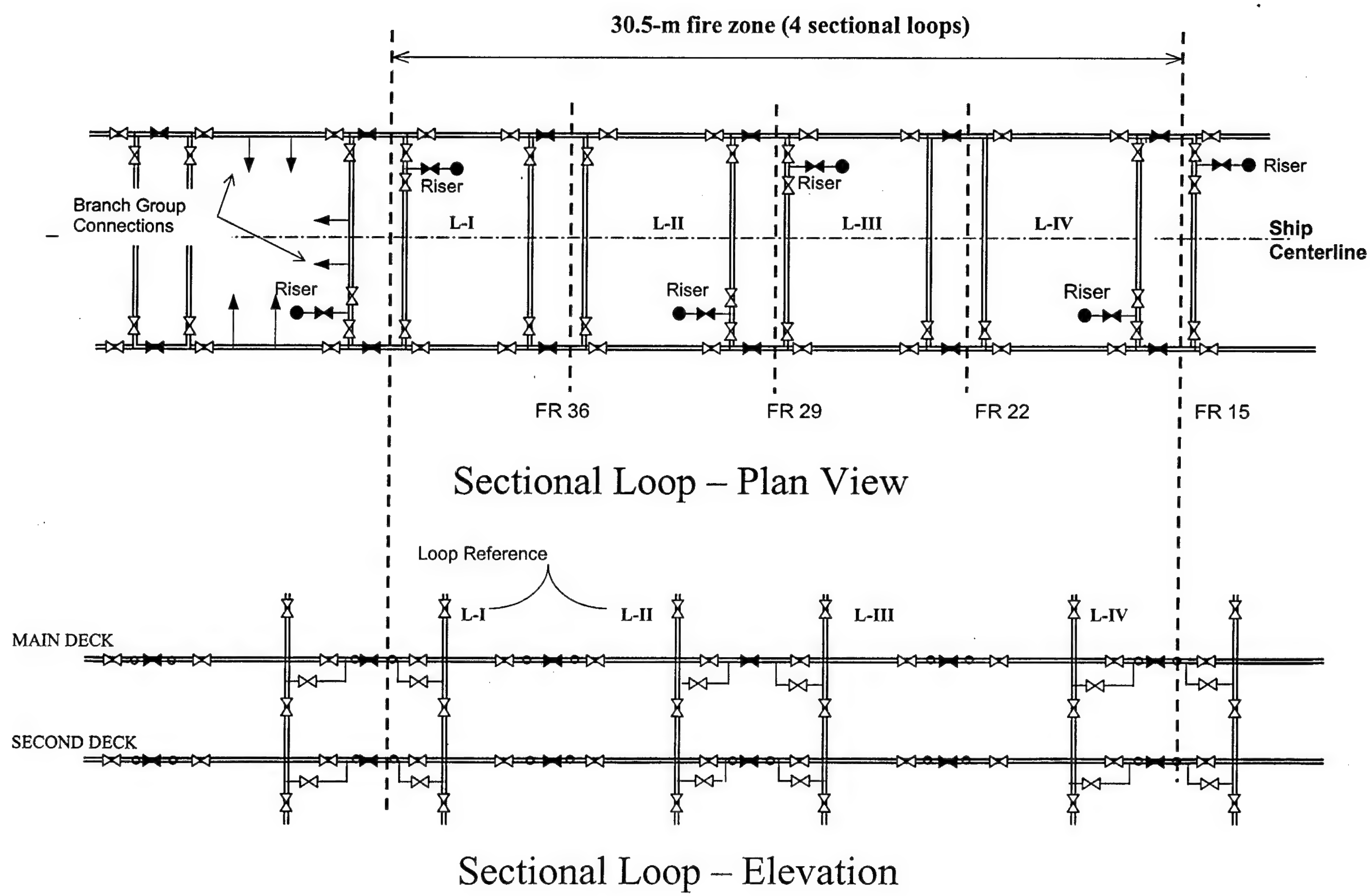



**Figure 8a - Piping schematic showing generalized sectional loop architecture, any deck**

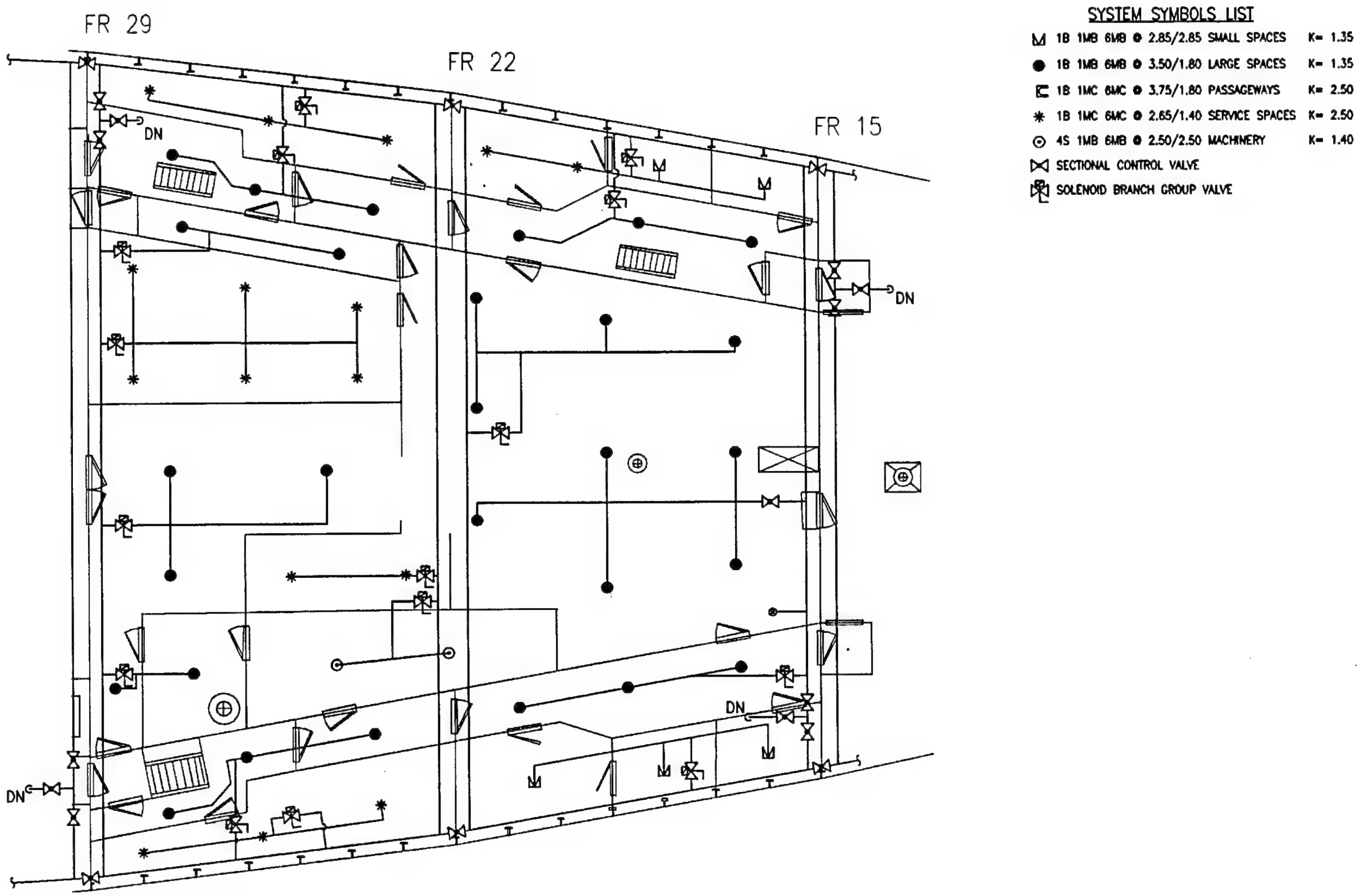



**Figure 8b – Sectional Loop piping layout, HP water mist system, Main Deck on ex-USS *Shadwell***

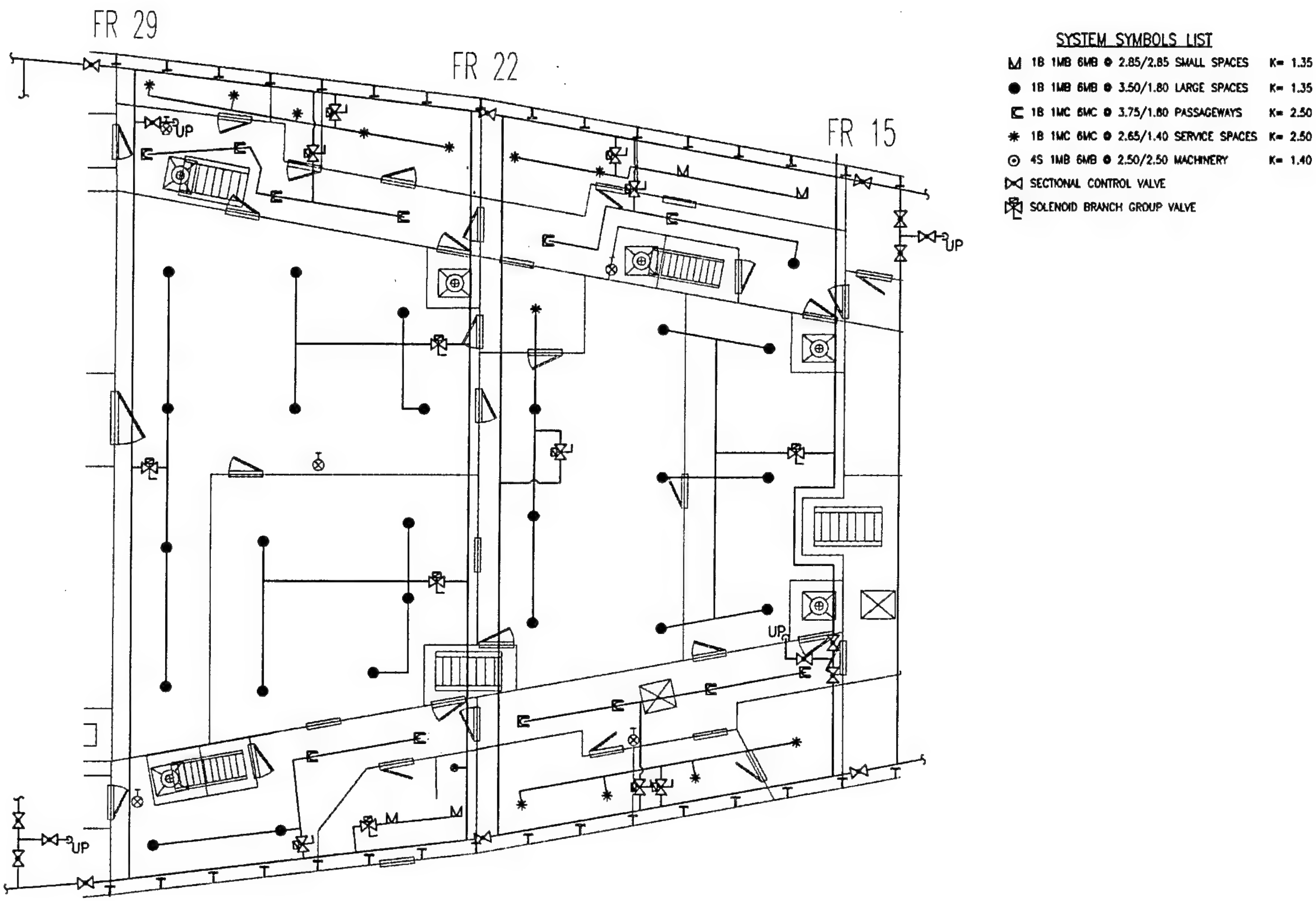



**Figure 8c – Sectional Loop piping layout, HP water mist system, Second Deck on ex-USS *Shadwell***

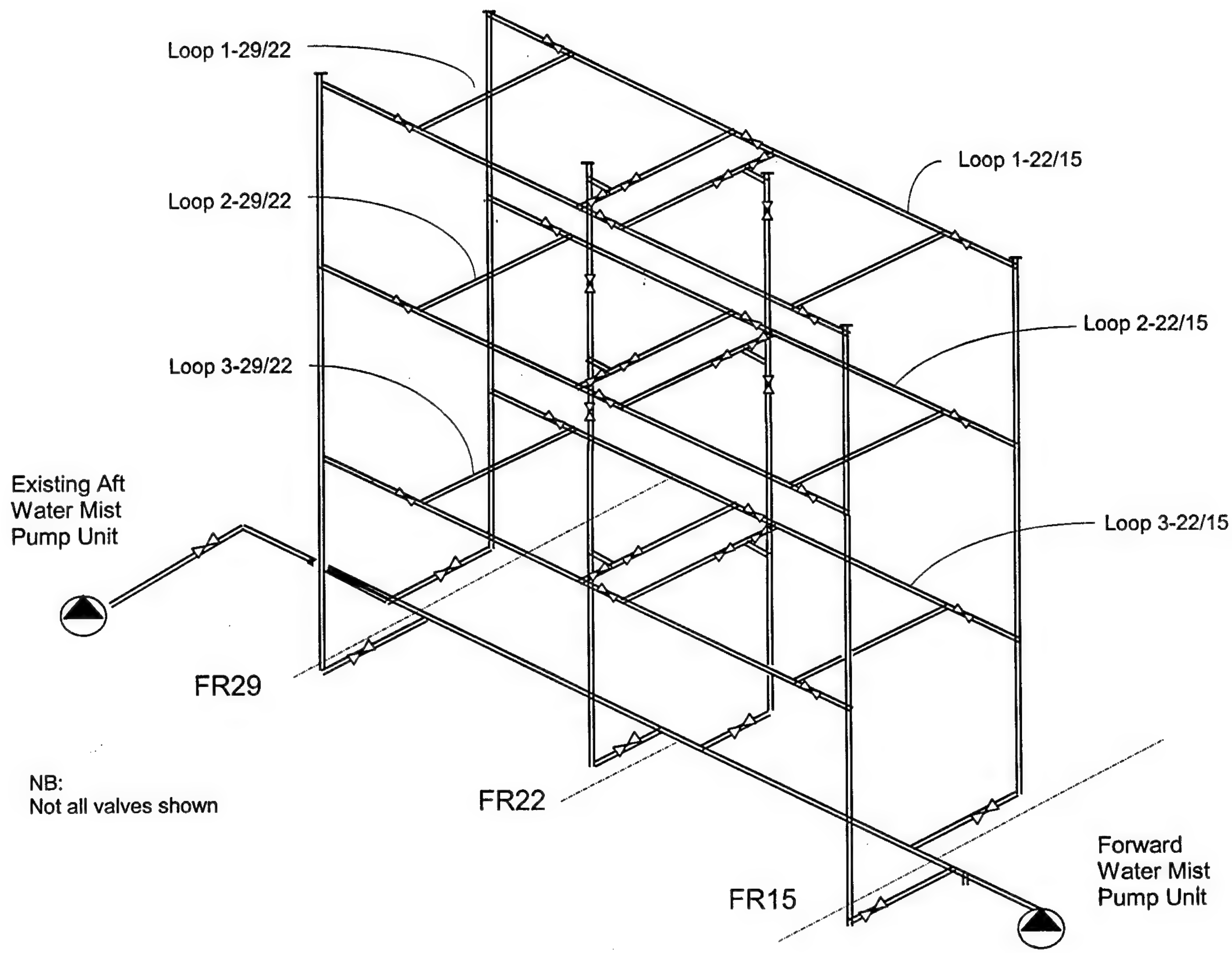



**Figure 8d – Isometric view of partial sectional loop distribution system piping layout on the ex-USS *Shadwell***

length of the ship, each riser serves both port and starboard sides of the ship. Unlike the dual main arrangement, crossover pipes connect the port and starboard mains to each other on the same deck level. Crossovers are more frequent than for the offset loop configuration. Two crossover mains are provided on either side of each watertight bulkhead separating sections along the length of the ship. Each crossover main is positioned to be as protected as possible against blast damage to the bulkhead. Valves are placed so that each sectional loop can be supplied in two ways:

a) with all supply coming up the riser serving that section, and nothing from adjacent loops, or

b) the riser can be closed off so that supply must come from one or both of the two adjacent sectional loops.

The sectional loop architecture incorporates positive features of the "dual main" and "offset loop" configurations, but it allows for subdivision of the system into small "cells" that can be individually isolated. This is expected to be a significant advantage for developing a fast recovery from blast damage to the piping system. The arrangement also has advantages for the hydraulics of the piping system, by increasing the number of pathways for water to flow to any demand point. A large demand to a given area will distribute itself over several risers and flow paths. This permits the use of smaller diameter pipe than either of the other options.

Branch groups can be connected to the sectional loop at any point, either in the outboard passageways or in the compartment itself. For hydraulic reasons and to facilitate installation, it is preferable to distribute the branch group connections conveniently around the loop. The perception is that if the valve survives, it will be possible to supply some water to nozzles in the damaged compartment. In fact, if branch group piping or crossover mains in a sectional loop are damaged by a blast in a compartment, it will not be possible to create the nozzle pressure needed. In that case, it doesn't matter whether the water mist control valves are in the passageway or in the compartment. Valves installed in the passageways, if they survive, will be able to activate nozzles in the passageway to help confine the fire.

The sectional loop piping system forms a three-dimensional grid of horizontal and vertical loops of 40 mm (1.5 in.) stainless steel pipe, with four sectional loops hence four risers per 30.5 m (100 ft) fire zone. Figure 8d shows an isometric view of the Sectional loop structure, as it will be installed on the SHADWELL. Each sectional loop is connected to its two neighboring loops such that there is a continuous flow path along the port and starboard sides of each deck, interconnecting all fire zones. Crossover mains in each section connect the port and starboard outboard mains. Eight branch connections are distributed around each sectional loop. Water is supplied via the risers from pumps located on the 4th deck.

Each of the three piping configurations requires valves to subdivide the system into segments. The spacing between valves determines the size of the area that will be non-functional if valves must be closed to isolate a rupture. Ideally, valves should be close enough together that they can be shut off precisely on either side of a rupture. The advantage gained by adding valves must be balanced against system cost and complexity. The following section discusses the logic for inserting valves into each of the three piping configurations to minimize the size of the

isolated area, so to have functional fire protection nozzles as close as possible to the blast damaged area.

## 2.5 Control Valve Arrangements (Main Valves)

A balance must be achieved between the benefits and the cost of installing valves in the distribution mains to isolate damaged areas. The DC-ARM objective is to achieve a reflexive network that will be able to sense that piping has been damaged, to close valves as necessary to isolate the damaged area, and to restore functionality to surrounding areas. The perimeter of the isolated areas due to closed valves should be as close as possible to the perimeter of the actual blast damaged area. At the same time, the system must continue to provide adequate flow to areas adjacent to the damaged area even if it is through longer-than-normal flow paths.

The objective of self-activated isolation of a rupture requires the introduction of an instrumented, motorized, and programmable sectional control valve at critical points in the distribution mains. These sectional control valves must permit two-way flow and have a low friction loss. The sectional control valve must be equipped with pressure sensors to read water pressure across the valve. It must have both a manual and a motorized actuator so that it can be operated locally, automatically or manually, or from a remote location. The controller or actuator for the valve must be programmable and of a sort that can be connected to a supervisory control system. These programmable sectional control valves are referred to as "smart valves." Data from the sensors must be self-interpreted by an algorithm residing on the programmable chip in the valve actuator, so that closing action can be initiated based on local analysis of local conditions.

The logic for determining the optimum number of valves for each of the system architectures is based on the following considerations:

1. The maximum level of control for isolating damaged piping and rerouting flows could be achieved by installing a valve on each end of every pipe connecting two separated grid points. For a T-intersection, this would mean having a valve on all three branches. This level of valving results in a high valve count. Strategies for eliminating any redundant or unnecessary valves obviously must be pursued. It must be kept in mind, however, that the objective is to develop a distribution system architecture with outstanding capacity to recover from blast damage, and to restore functionality on the very perimeter of the primary blast area. It is anticipated that this "recoverability" aspect will be closely tied to Operational Requirements Document (ORD) criteria to restore ship mission capability. The number of valves directly defines the size of the isolated portion of the system. This design temporarily suspends the issue of what constitutes "too many valves." It proceeds on the basis that valves will be placed where needed to meet the recovery objective. Innovative means of reducing cost and complexity of the valve structure will be pursued later.

2. The determination of the location and number of valves needed to achieve the recovery objectives is not dependent on completion of the logic algorithm for rupture isolation. The logic algorithm by which smart valves determine that they should close or remain open is under development for FY 01.

Working from diagrams of a single deck of a hypothetical fire zone, damage assessments were performed for each arrangement and different numbers of smart valves. The diagrams were based on a total of 4 sections per fire zone, 8 branch groups per section, and 32 branch groups per fire zone per deck. "Survivability" under a given damage scenario was quantified by counting the number of functioning branch groups per deck in a fire zone of the ship after all valves necessary to isolate the damaged area had closed. The result was expressed as a percentage of the total number of functional branch groups in the fire zone.

The damage scenario was assumed to be a primary damage area 18 m (60 ft) long, extending transversely over to the main on the opposite side of the hit, but not damaging the main in the opposite passageway [3]. Although the damage would extend vertically for three decks [3], damage evaluations done on a "per deck" basis were sufficient for comparison purposes. All branch group piping in the primary damage area was assumed to be non-functional, either because the valve and supply main were destroyed on the side of the hit, or because the branch group piping itself was destroyed within the compartments. Even if the valve and supply main for a particular group of nozzles are in the undamaged passageway, water cannot be supplied to nozzles in the compartment if the interior branch piping is broken. Figure 9 illustrates the method of determining survivability of a generalized schematic of the Sectional loop architecture on a single representative deck, with different numbers of control valves. Similar accountings of surviving branch groups were done for the Center Main and Dual Main designs, but are not shown.

Table 5 compares the outcomes for survivability counts for the three system architectures for the valve choices described. It was decided that the most important objective for this development stage was to maximize the functional area after blast damage. The highest percentage of functional branch groups achieved was 50 percent. Both the Dual Main and sectional loop architectures achieved 50 percent survivability. For the Dual Main/Offset Loop, however, if the blast damage happened to include one of the offset crossover mains, the percent survivability could reduce to less than 25 percent. For the sectional loop design with the ideal number of valves, the primary damage area could be anywhere in the fire zone and 50 percent survivability would still be achieved. With reduction in the number of valves, the percent survivability decreased.

Table 5. Comparison of "Survivability" of Three Architectures for an 18-m (60-ft) Primary Damage Area, Port Side, One Deck

| Option | Description | Number per fire zone per deck [Note 1] | Number Functional [Note 2] |
|---|---|---|---|
| Center Main | See Figures 6a, 6b and 6c<br>Main along center axis of ship<br>Water mist control valves at center main<br>8 Branch groups per Section, 4 – port, 4 - starboard<br>4 Sections per 30.5 m (100 feet) fire zone<br>2 Supply Risers 75 mm (3 in.) diameter per fire zone<br>Tree architecture (mains 65 mm (2.5 in. diameter) | 10 Main valves<br>32 Branch valves<br>2 Risers | 8 Branch groups<br>12.5 %<br><br>1 Riser<br>50% |
| Dual Mains (includes offset loop) | See Figures 7a, 7b and 7c<br>Mains in port & starboard passageways or outboard<br>Branch groups inboard to mid-ship<br>8 Branch groups: 4/port + 4/starboard passageways<br>4 sections per 30.5-m (100 feet) fire zone<br>4 supply risers 75-mm (3 in.) $\phi$ per fire zone<br>Tree architecture (mains 65 mm (2.5 in. diameter)<br><br>*Note: Damage to a crossover main / riser could reduce the survivability to < 25 percent.* | 16 Main valves<br>32 Branch valves<br>2 Risers – port<br>2 Risers - starboard | 16 Branch groups<br>50 % (see note)<br><br>1 Riser - port<br>2 Risers – stbd<br>75 % |
| Sectional Loops | See Figures 8a - 8d and Figure 9<br>Port & starboard mains interconnected at bulkheads<br>4 Sections per 30.5 m (100 feet) fire zone<br>8 Branch groups per section<br>4 Supply risers per fire zone (1 per section)<br>Loop architecture (mains 38 mm (1.5 in.) diameter) | 48 Main valves<br>32 Branch valves<br>4 Risers | 16 Branch groups<br>50 %<br>3 Risers:<br>75 % |

*Note 1. The count is based on four sectional loops per fire zone, per deck.*
*Note 2. The number of functional branch groups of nozzles per fire zone quantifies "survivability."*

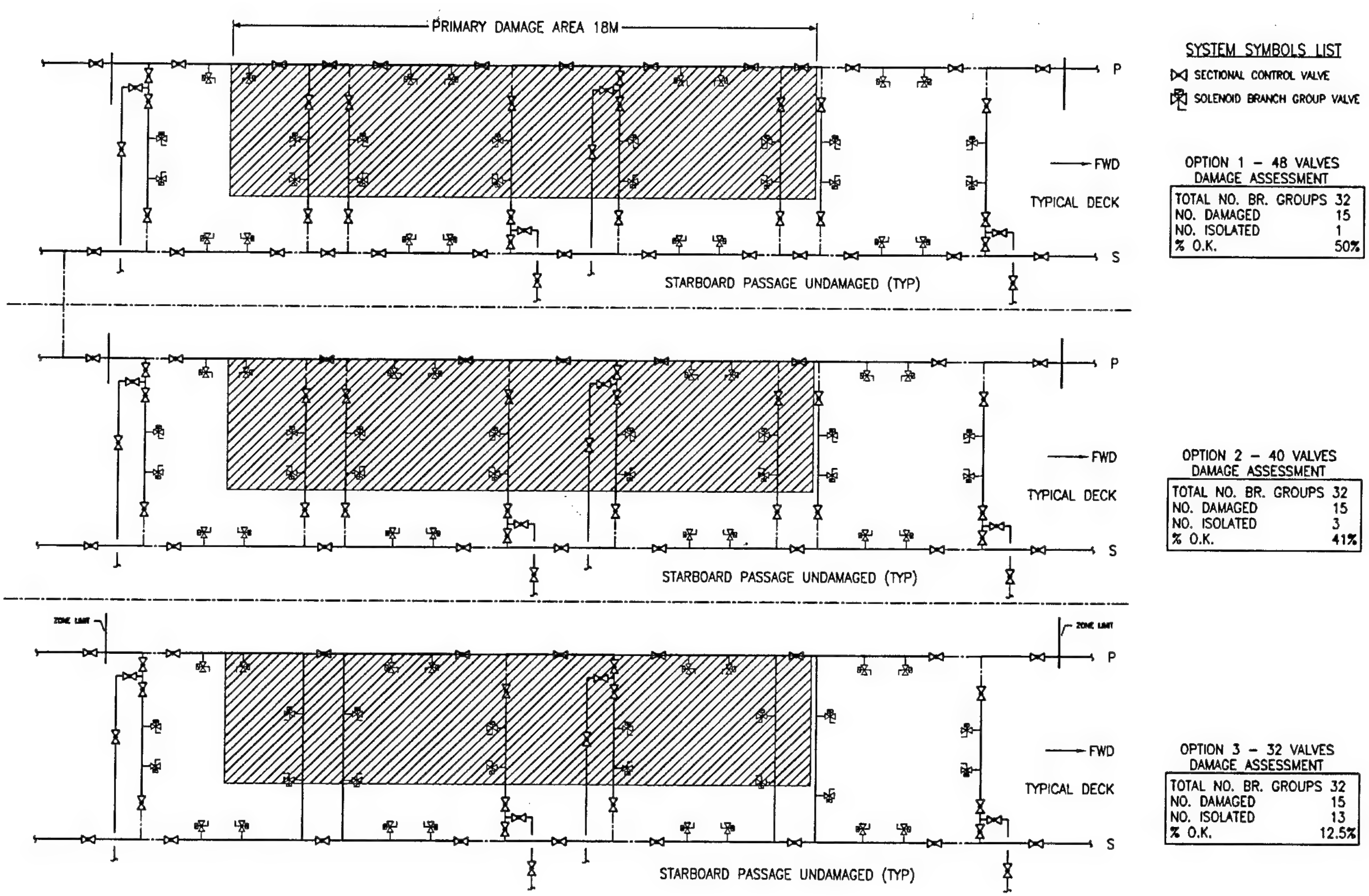



**Figure 9 – Sectional loop damage assessment diagram**

This evaluation did not compare the cost of the different types of systems. Factors such as system cost, complexity and maintainability would be addressed at a future time. Some of the potential disadvantages may be eliminated or reduced after the potential benefits of the concept are fully evaluated.

Several factors favored the sectional loop concept over the dual main/offset loop. The interconnected loops provide multiple flow-paths; hence reduce friction losses, which in turn permit the use of smaller diameter distribution pipe than the other arrangements. Also, a preliminary draft of the rupture isolation algorithm is based on the advantage of having multi-deck sectional loops on a single riser. If the intersectional control valves between sectional loops on each deck are closed (either normally or for a battle-ready condition) all flow to a ruptured zone must go up a single riser. The large flow combined with an inability to reestablish a minimum system backpressure will be easily recognized as a rupture signature. It will only be necessary to close the inter-deck control valves on that riser to isolate the ruptured loop (and a few intact loops) supplied by that riser. The rest of the system in adjacent sectional loops will be restored to full operating capability within less than 30 seconds. Then, inter-sectional control valves on the decks will successively partially open to "explore" whether the neighboring isolated loop is intact or otherwise. If intact, the pressure will rise to equal the pressure in the rest of the system, $\Delta P$ across the valve will go to zero, and the valve will "decide" to open fully. If the pressure does not rise to a threshold value within a certain time, the valve will "decide" the loop is ruptured and will re-close. In this way, any intact loops in a vertical section that were isolated by the initial closing of riser valves will be supplied from the neighboring sectional loop or loops.

The sectional loop architecture has the following desirable properties:

1. The three-dimensional grid with multiple flow paths provides a hydraulic advantage, permitting use of smaller diameter pipe for the distribution mains and tubing for branch lines than the alternative designs.

2. Numerous transverse pipes (crossovers) provide convenient connection points in mid-ship areas. This feature can increase the number of functional nozzle groups under some damage scenarios.

3. The survivability of branch groups (50 percent per fire zone with the maximum number of main control valves) was less dependent on adverse or fortuitous location of the blast damage relative to crossover mains than Dual Main/Offset Loop.

4. The arrangement has characteristics that are expected to simplify recognition and rapid isolation of a rupture.

On the basis that it provided at least three significant advantages over other arrangements, the sectional loop architecture was selected as the most favorable arrangement for a survivable distribution system.

Figure 9 illustrates an exercise to determine the optimum number of smart valves to achieve the desired performance level of the sectional loop architecture. The information is tabulated in Table 6. Four sectional loops utilizing 48, 40 and 32 smart valves per deck per fire zone were evaluated for survivability under the previously described damage scenario (18 m (60-ft) damaged area, port side). The maximum achievable survivability for the damage scenario (50 %) was obtained using 48 Smart Valves per Fire Zone. That corresponds to the maximum number of valves possible at each T-intersection in the grid. The number of valves is reduced to 40 by eliminating two of the five valves at the point where the intermediate pair of crossover mains intersects the port or starboard mains. The number of functional branch groups drops to 14, or 41 percent, indicating that the extra valves had value. A further reduction in the number of valves to 32 was accomplished by eliminating the valves on the crossovers at the same intersection. The number of functional branch groups drops to 4 out of 32, or 12.5 percent.

The decrease in functionality with reduced number of sectional control valves is due to the fact that increasing the distance between closed valves isolates more undamaged branch groups. It is also interesting to note in Table 6 that if all of the water mist control valves are located in the port or starboard passageways, rather than distributed around the loop, the percent-functional branch groups for the 32-valve scenario drops to *zero percent*. All nozzles in the fire zone on that deck will be isolated from the water supply. This observation highlights the fact that the sectional loop configuration provides four "mains" in each section, as opposed to only two for the dual main arrangement. Some functionality is preserved if a crossover main is still functional. In this specific scenario, there is no advantage in forcing all connections to the port and starboard mains.

Table 6. Survivability of Sectional Loop Architecture with Different Numbers of Smart Valves

| All counts are per 4-Section Fire Zone | 48 Valves | 40 Valves | 32 Valves BGs on loop | 32 Valves BGs in Passage |
|---|---|---|---|---|
| # Branch Groups - Total | 32 | 32 | 32 | 32 |
| # Branch Groups Damaged | 15 | 15 | 15 | 15 |
| # Branch Groups Isolated | 1 | 3 | 13 | 17 |
| % Branch Groups Functional | 50 % | 41 % | 12.5 % | 0 % |
| # Smart Valves Damaged | 15 | 11 | 9 | 9 |
| # Smart Valves to Close | 8 + 2 on riser | 8 + 2 on riser | 5 + 2 on riser | 5 + 2 on riser |
| # Risers | 4 | 4 | 4 | 4 |
| # Risers Damaged | 1 | 1 | 1 | 1 |
| # Risers Isolated | 0 | 0 | 1 | 1 |
| % Risers Functional | 75 % | 75 % | 50 % | 50 % |

Table 6 also shows the effect of reducing the number of sectional control valves on the number of risers that are affected by the blast damage. Again, having too few control valves means that an otherwise undamaged riser will be isolated. If three out of four risers are available to flow water, the friction loss in each riser will be less than if only two out of four are available.

The full contingent of sectional control valves helps maintain the hydraulic advantages inherent in the looped system.

## 2.6 The "Valve Node"

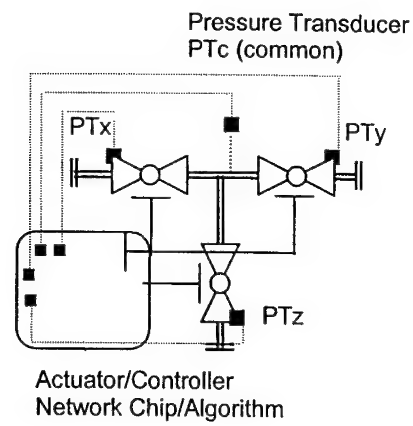
Section 2.5 illustrated that the maximum flexibility in a gridded piping system would be achieved if every intersection of three pipes (node) were to have a valve on each leg. It is possible to devise schemes to delete one or more of the three valves in the interest of reducing cost, but with each reduction the potential of the system with respect to "survivability" is reduced. However, an alternative approach would be to reduce the cost of the valves, so that a hydraulic system could afford three valves at each T-intersection. It is proposed to treat each intersection as a "Valve Node" by consolidating actuators and logic circuits into one housing, capable of operating each valve individually. The intent is to take advantage of the proximity of the valves at each intersecting node in the pipe network to achieve some economies of design. Figure 10 is a conceptual diagram of the "valve node."

Applying the Valve Node consolidation to Figure 9, the 48 individual smart valves in the top diagram become 20 "valve nodes," with some 2- and some 3-valve nodes.

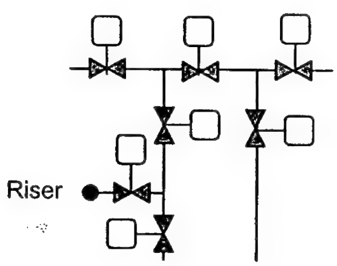
## 2.7 Branch Group Control Options

Figure 11 shows two approaches to controlling flow to individual nozzles in the system. The upper diagram shows a normally closed solenoid operated Water Mist Control Valve (WMCV) connected to a branch line of open or deluge-type nozzles. The FY 00 DC-ARM demonstration will utilize this approach. The command to cause a solenoid operated WMCV to open will be given by an operator responding to information from an independent fire detection system. Nozzles that are individually thermally actuated, however, are more "reflexive" than a system of open-nozzles connected to an independent detection system. That is, the nozzle will react to heat in the compartment and open if it becomes hot enough, without the need for any human action. Figure 11 illustrates the concept of a specially designed Hybrid Water Mist Control Valve (HWMCV) that permits the use of nozzles that can be both thermally and mechanically released.

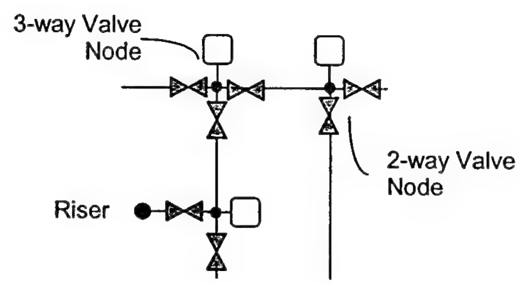
| | |
|---|---|
| Pipe Size: | 40-mm nominal, S-40 SS; 600 # flanges |
| Medium: | Freshwater at 10°C - 50°C |
| Operating pressure: | Normal 65 to 80 bar; Maximum 100-bar |
| Valve Type: | Low friction loss e.g., full throat ball valve |
| Material: | Stainless steel |
| Pressure transducers: | 0 –100 bar upstream & downstream, ± 2% FS |
| Full-turn close/open: | 5 seconds under ΔP = 100-bar |
| Flow direction: | Two-way flow, all branches |
| Flow Range: | Normal 10 to 400 L/min |
| | Extreme: 800 L/min (velocity ~ 10 m/s) |
| Program: | LONWORKS or equivalent |
| | Gauge pressure \|Px-y-z\|, ΔPx-y-z, Qx-y-z |
| Explore: | Partially open, check P, Q, Full Open, Close |
| Power Requirement: | 208 VAC/60 Hz available |




**3-Way Valve Node**




7-Valve Intersection




3 Node Intersection

**Figure 10 – Conceptual elements of a "valve node" for a pipe network**

In order to pre-wet and cool a compartment on the boundary of a fire before fire spreads into the compartment, an operator must be able to actuate nozzles remotely without waiting for temperature activation. The open nozzle/solenoid WMCV concept provides that level of control. With the thermally released nozzles, such pre-emptive activation of nozzles is more difficult, but there are several means of achieving it. For example, a hydraulically or electrically activated pin can be mounted on the nozzle to break the thermal link or glass bulb. Additional pilot tubing or electrical control wire must be run between the HWMCV and each nozzle it controls. Both the nozzle and the HWMCV must be custom designed to permit this dual action. A hybrid nozzle and WMCV design may be considered for the FY 01 DC-ARM demonstrations.

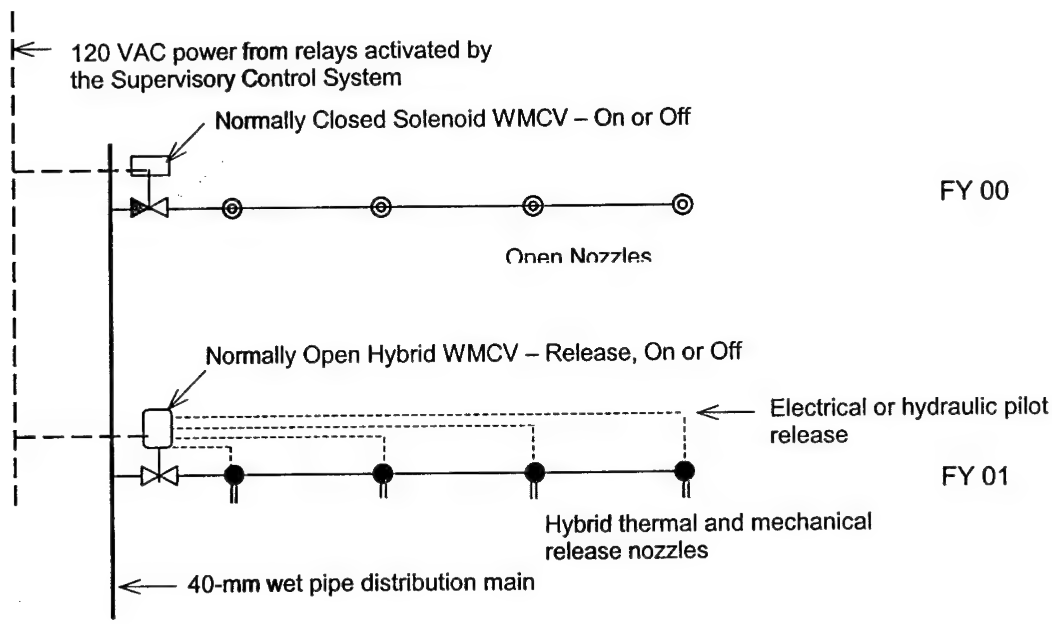



**Figure 11 – Branch group control options for FY 00 and FY 01**

## 2.8 Summary of Sectional Loop Design Features and Rationale

Sections 2.1 to 2.7 of this report described the approach to the design of a HP water mist fire suppression system for a Navy ship. The design was based on applying nozzle spacing rules established by IMO for commercial passenger ships to the deck plans for the SHADWELL, forward of Frame 29. The IMO performance objective is stated to be "fire extinguishment." From that specific layout, a generalized layout emerged involving typically 30 nozzles per "section," 4 nozzles per "branch group," and 8 branch groups per section, and 4 "sections" per "fire zone." Based on an analysis that showed the HP water mist system to require about one-half the water flow demand of a low-pressure water mist system (presented in Appendix A), a HP water mist system was selected. (The lower water demand permitted greater flexibility in design of the distribution system). Total water flow demands were calculated based on the sum of water demands for different numbers of branch groups, depending on assumptions about peacetime

fires or wartime scenarios. A pumping strategy was recommended, namely, one HP pump unit per fire zone, installed at the lowest deck level, each pump unit sized for one-third of the maximum design demand flow for the ship. With the basic features of nozzle count, water flow demand and water supply established, options for design of the distribution system were investigated.

The scope of the distribution system design encompassed more than simply meeting the hydraulic requirements of flow and pressure to the most remote nozzles. The design sought an arrangement for valves and piping that would be capable of surviving significant blast damage while retaining functionality of the system as close as possible to the primary blast area. By incorporating "smart valves" it was intended that valves be capable of self-diagnosing that a rupture has occurred, and shutting themselves off to isolate the rupture. Three options for distribution system design were evaluated. These were described as "Center Main," "Dual Main" and "Sectional Loop" architectures. A diagram showing the arrangement of mains, risers control valves and branch group loads was presented for each option.

The performance of one option over the other was compared by counting the number of functional branch groups of nozzles in a 30.5-m (100-ft) fire zone after "blast damage" had taken out piping within an 18 m (60 ft) length of the zone. This "percent functional" value was equally high (50 percent) for the "Sectional Loop" and the "Dual Main" architectures. This apparent equivalency however does not reflect the hydraulic advantage that the sectional loop arrangement provides over the dual main architecture. As the distance from the demand point increases, the number of loops available for distribution of flow is significantly larger for the sectional loop arrangement than for the dual main. For the same relative locations of pump units and demand point, the total friction loss will be at the least for the system with the greater number of flow paths. One can profit from the reduced friction loss either by reducing the pumping energy requirement, or by reducing the distribution system pipe size for the same energy requirement. In this case, the choice was in favor of reducing the pipe sizes. For this reason, the sectional loop arrangement had hydraulic advantages that counter the equivalency in terms of survivability with fewer control valves.

It was noted that the sectional loop architecture allows for subdivision of the system into small "cells" that can be individually isolated, or supplied from alternate routes. This is expected to be an advantage for developing a fast recovery from blast damage to the piping system. Work on the algorithm for diagnosis and recovery from rupture will be performed in FY 01.

Disadvantages of the Sectional Loop architecture include the labor and material for installation of the extra crossover mains, and the cost invoked by the large number of valves relative to the dual main arrangement. In the interest of reducing the cost of valves, it was proposed to treat each intersection as a "valve node" by consolidating actuators and logic circuits into one housing, capable of operating each component valve individually. The intent is to take advantage of the proximity of the valves at each intersecting node in the pipe network to achieve some economies of design. A conceptual diagram of the "valve node" was presented. It is expected that industrial valve manufacturers may be able to fabricate a prototype valve node for the FY 01 experimentation on the SHADWELL.

Based on the analysis presented, the sectional loop architecture is recommended for meeting the reduced manning objectives of the DC-ARM program. The important design features of the recommended water mist system are summarized in Table 7.

## 3.0 WATER MIST SYSTEM DESIGN FOR FLASHOVER SUPPRESSION

Section 2 of this report adapted the IMO spacing rules for layout of the nozzles. The performance objective was "extinguishment." In this Section, the water mist system was re-designed based on meeting the flashover suppression objectives described in Phase I of the DC-ARM test program [1]. Horizontally oriented HP nozzles were located along compartment walls, rather than distributed in the interior space of each compartment following IMO spacing rules. Nozzles were located directly over doors or hatches to interrupt airflow into the compartment as much as possible. It is intended that nozzles spraying into the compartment mix and cool the fire gases. In the ventilation limited compartments typical of ship berthing areas, the combination of mixing and convective cooling, increasing water vapor, reduced oxygen levels, plus some fuel wetting restrain fire growth and limit temperature rise.

Setting flashover suppression as the primary objective has the potential to reduce piping materials and installation labor, decrease total water flow demand, permitting use of smaller diameter pipe and reducing system weight and cost. This Section quantifies the differences between a system laid out for flashover-suppression objectives and one laid out to the IMO-objectives.

### 3.1 Nozzle Layouts for Flashover Suppression

The Phase I fire tests confirmed that compartment temperatures could be kept below flashover temperatures using widely spaced nozzles. The Phase I report [1] recommended that: for small compartments (~25 $m^2$) a single nozzle over the door can prevent flashover. For larger compartments, vertically oriented nozzle spray cones may be spaced to "cover" no more than 20 percent of the deck area. For the SHADWELL installation, it was desired to use horizontally mounted nozzles along the perimeter of each compartment aimed to discharge toward the middle of the space. In the absence of any commercial system design criteria for a "flashover suppression" application, spacing rules for a nozzle layout were generated based on the Phase I report recommendations, and on data relating to horizontal mounting of commercially available water mist nozzles.

Table 7. Summary of HP Water Mist System Design Criteria – Sectional Loop Architecture – IMO Nozzle Spacings (Extinguishment Objective)

| Feature | Description | Quantity | Comment |
|---|---|---|---|
| Ship Subdivision | Fire zones defined by bulkheads<br>Sections – defined by watertight bulkheads<br>Compartments – defined by partitions | 4 fire zones per ship<br>4 Sections per fire zone<br>Variable # per section | Based on SHADWELL deck plans, but generalized. |
| Nozzle spacing | Distances between nozzles and from walls as per manufacturer's IMO test approval | 30 nozzles per Section per Deck | Nominal count |
| Nozzle grouping | Nozzles grouped into branch lines (Branches) by compartment, and parallel with frame lines, | 3 or 4 nozzles per Branch<br>3 Branches per large compartment | Fire encounters water mist curtain across full beam width of ship. |
| Nozzle Group Control | Solenoid WMCV for Open Nozzles:<br>Hybrid WMCV for Glass Bulb + remotely actuated nozzles<br>WMCV's distributed around 4 sides of Sectional Loop | 25-mm Solenoid valve<br>25-mm Special Hybrid valve & nozzles<br>Nominal 8 BGVs per Section | Normally Closed<br>Normally Open + pilot lines to nozzles. |
| Design Flows | Maximum Demand – wartime damage scenario, two decks fore and aft of blast damage, plus deck above | 90 L/min per Branch Group<br>1344 L/min per 16 BGVs | 16 BGV = 3 each on 2 decks, fore and aft of damage, plus 4 in comp't above. |
| Type of System | HP, wet pipe to WMCV freshwater source | Design nozzle pressure 70 bar (1015-psig) | |
| Pumping Strategy | HP positive displacement pump units in parallel at 4-deck level connection to common header and multiple risers | 4 - pump unit / ship<br>1 – pump unit / fire zone | Each pump unit sized for 1/3 total demand:<br>448 L/min @ 80 bar |
| Distribution piping | Sectional Loop Architecture<br>Three dimensional, multi-loop grid consisting of risers, port & starboard mains and crossover mains at bulkheads | 40-mm nominal pipe for risers and mains.<br>40-mm crossover mains on each side of each water tight bulkhead | One pipe size for entire system.<br>Crossover mains tight to overhead, protected by bulkhead. |
| Valve Concepts | Based on one valve on every branch of a T-intersection, at both ends of crossover mains, separating each sectional loop, and on risers separating each deck level | 48 Sectional control valves per Fire Zone per Deck - or<br>20 Node Valves per Fire Zone per Deck | Valves in risers count in more than one "set" and are not included in count of 48. Add 1 valve per riser per deck. |
| Performance | Survivability<br>Response to 20-m (65-ft) blast area in 30.5-m (100-ft) Fire Zone, one deck | 50 % of Branch Groups Functional | |
| Performance | Rupture Isolation: | Algorithm to be developed | |

In the Phase I fire tests, an HP nozzle designated "4S 1MC 8MB 1100" ("4S-1100") provided better suppression than the other HP nozzle (Navy Nozzle) [1]. The 4S-1100 nozzle discharged downward during these tests. This same nozzle is listed by the Factory Mutual Research Corporation (FMRC) for use in gas turbine/machinery enclosure suppression systems, where it may be installed in a horizontal orientation. If installed horizontally, the FMRC listing allows a distance between nozzles of 7.5-m (25 ft). The listing also specifies a maximum width of compartment for horizontal projection of 12.5-m (41 ft), in which case there must be one horizontally oriented nozzle on each end wall.

The 4S-1100 nozzle is a normally open deluge style nozzle with a 90°-cone angle. A thermally activated nozzle, the "1B-1MC 6MC-1000," was considered as well. The IMO-based system described in Section 2 of this report was laid out with nozzles in "branch groups" controlled by a normally closed solenoid valve. For the FY 00 test program, a solenoid operated branch group valve will be used with open nozzles. Such an arrangement is also suitable for the use of horizontally mounted open (4S-1100) nozzles in the flashover suppression design. However, nozzles mounted at the compartment perimeter will not respond as quickly to heat as nozzles that are distributed at the overhead of the compartment. For the IMO-design, it will be possible to use thermally activated nozzles. However, for the flashover suppression design, the conversion to individually thermally activated nozzles might introduce a delay in response. It is likely that the use of open nozzles with solenoid branch group valves will be the preferred mode of operation for a system designed for the flashover suppression objective.

Table 8 summarizes the spacing rules used to position water mist nozzles to achieve flashover suppression as measured in Phase I testing. Nozzle locations based on the spacing rules of Table 8 are shown in Figure 12a Main Deck, and Figure 12b Second Deck. As discussed in Section 2, the width of the ship narrows between Frame 29 and Frame 15, so the number of nozzles between Frames 29 and 22 is greater than the number of nozzles between Frames 22 and 15. The actual nozzle layouts in Figures 12a and 12b are used solely as a basis for a generalized arrangement for a typical section of a Navy ship. Figures 13a and 13b groups the nozzles into "Branch Groups" supplied from a sectional loop main architecture.

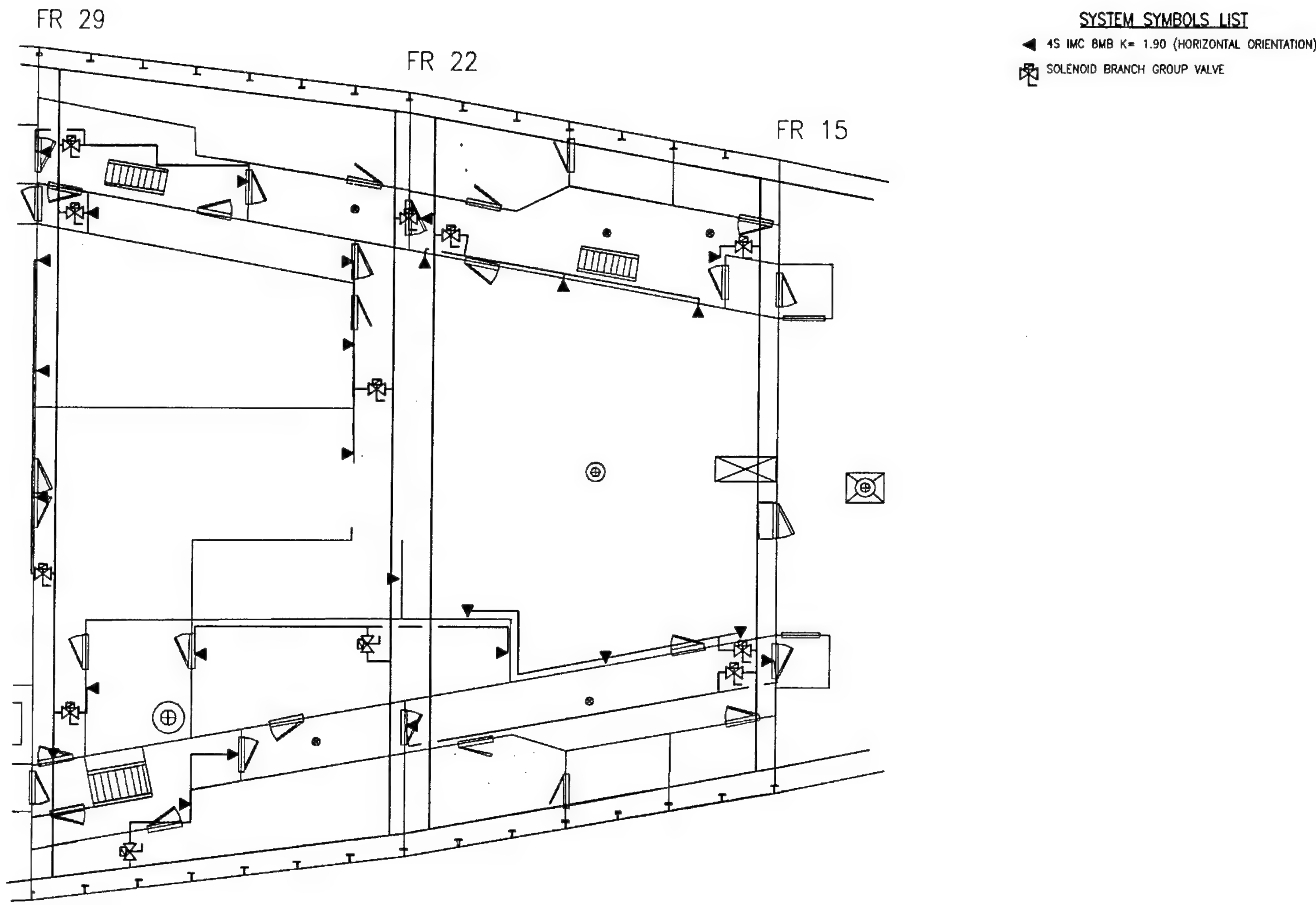



**Figure 12a – Nozzle layout for flashover suppression, Main Deck**

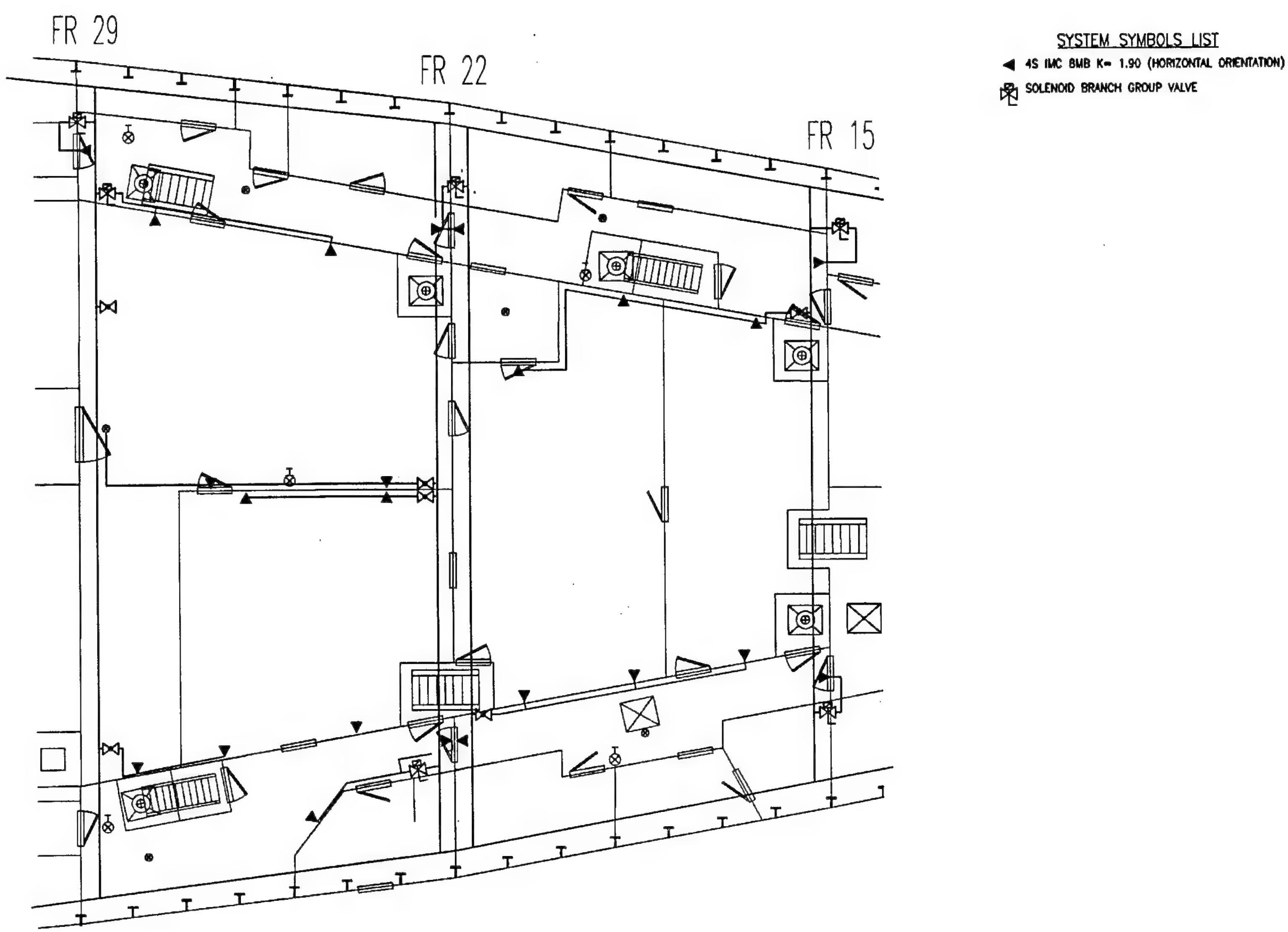



**Figure 12b – Nozzle layout for flashover suppression, Second Deck**

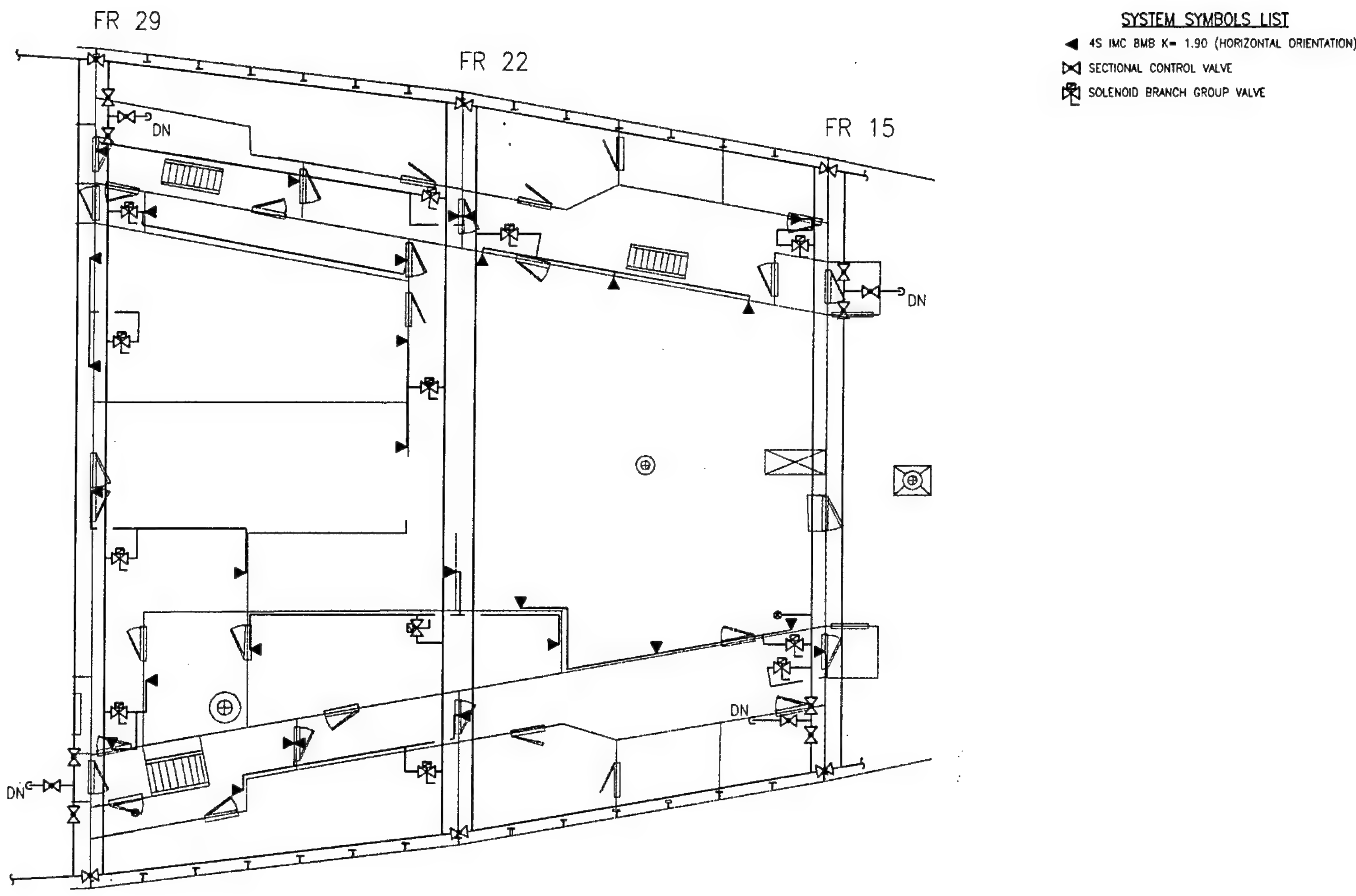



**Figure 13a – Trial branch groupings, Main Deck, HP water mist system designed for flashover suppression**

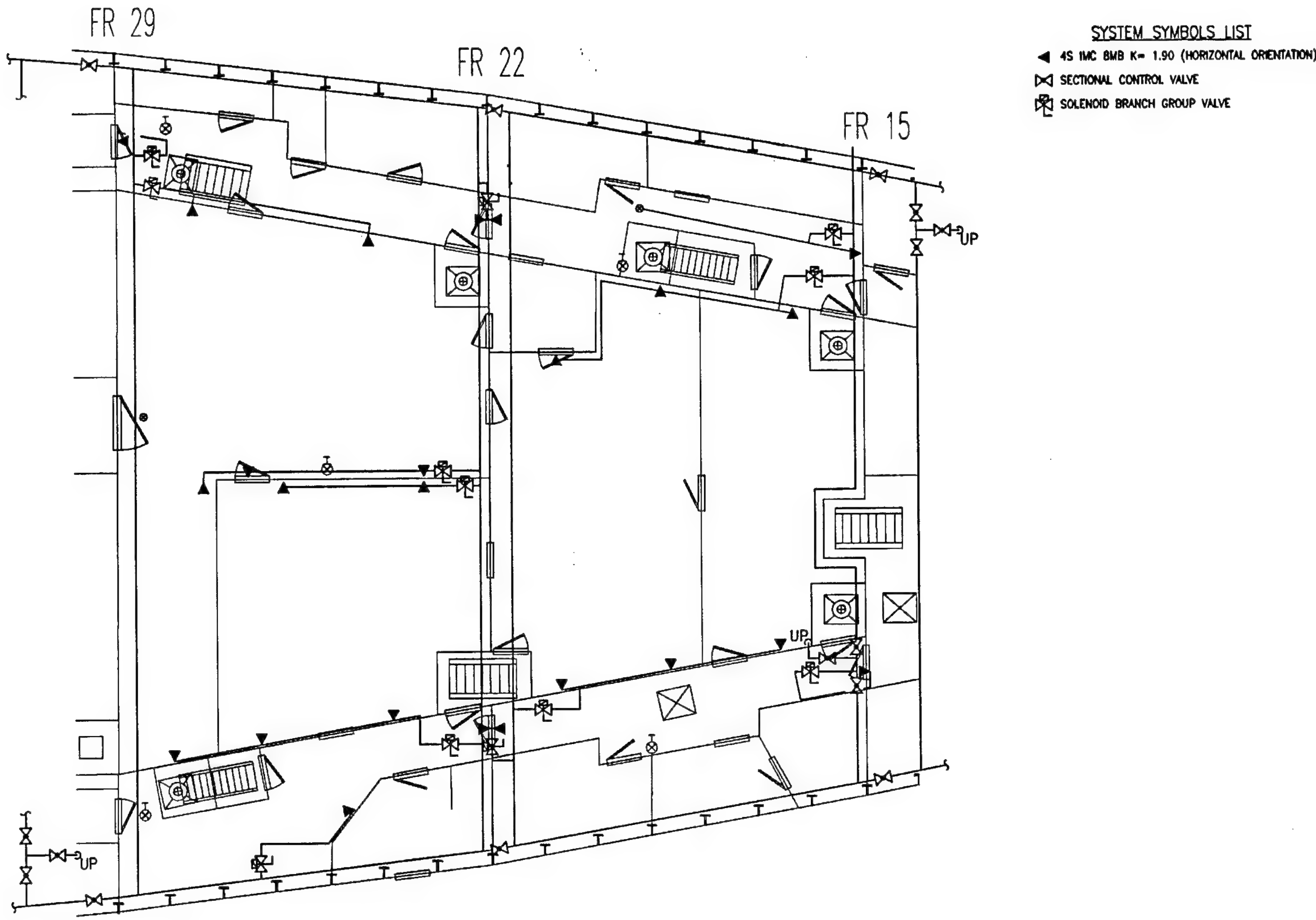



**Figure 13b – Trial branch groupings, Second Deck, HP water mist system designed for flashover suppression**

Table 8. Comparison of Nozzle Spacing Rules for a Water Mist System Layout for Flashover Suppression and Extinguishment Objectives

| Parameter | Flashover Suppression | Extinguishment Objective |
|---|---|---|
| Nozzle Designation | 4S 1MC 8MB 1100 | 1B 1MC 6MC 1000 |
| Maximum compartment height | 2.5 m | 5.0 m |
| Glass Bulb (GB) or Open | Open | GB |
| K factor | 1.9 Lpm/bar$^{1/2}$ | 2.5 Lpm/bar$^{1/2}$ |
| Discharge at P = 70 bar | 15.9 L/min | 20.9 Lpm |
| Max. length of compartment (Note 1) | 12.5 m | N/A |
| Distance from bulkhead, max | N/A | 1.90 m |
| Vertical orientation (Note 2) Max. distance below overhead | 4.0 m between nozzles 0.1 m below overhead | 3.75 m between nozzles |
| Horizontal orientation Note 3 Min. / Max. below overhead | 7.5 m between nozzles 0.3 to 0.9 m below overhead | 7.5 m between nozzles, Varies |

*Note 1:* *A compartment 12.5 m (41 ft) or less in width may be protected by installing horizontally oriented nozzles on opposite bulkheads. If wider than 12.5 m (41 ft), additional nozzles are needed to protect the middle area of the room.*
*Note 2:* *"Vertical orientation" refers to overhead mounted nozzles discharging vertically downward.*
*Note 3:* *"Horizontal orientation" refers to bulkhead-mounted nozzles discharging horizontally.*

## 3.2 Water Flow Requirements

Table 9 is a tabulation of the nozzle and branch group counts for the areas between Frames 15 and 29 on the Main and Second Deck of the SHADWELL for both a "flashover design" and an "extinguish design." It was assumed that the maximum number of nozzles of those counts is representative of a "typical" section on a generic ship. Table 10 shows the generalized design values for number of nozzles per section, and number of branch groups per section, and number of nozzles per branch group, for a generic ship. The calculated water flow rates for the generalized branch groups, assuming all branch groups have the same number of nozzles, are also shown in Table 10. The nominal flow per branch group for the flashover suppression objective is 48 L/min, whereas it was 84 L/min for the extinguishment objective. Assuming that this scale of reduction holds overall, significant reductions in pipe size and pumping capacity could be realized.

In Table 11 the calculated total design flows for various scenarios are shown, again for both options. The calculation assumed a total of 16 branch groups operating simultaneously for the wartime damage condition, as was used in Section 2. This corresponds to 3 branch groups on each of two decks, fore and aft of the fire zone, plus 4 branch groups operating in the compartment directly above the primary blast area. The machinery space water flow demand is also shown in Table 11. It is assumed that under peacetime conditions, the machinery room demand would not be simultaneous with 16 branch groups operating elsewhere in the ship. However, under wartime scenarios, the simultaneous demand is realistic. Therefore, the water supply (sizing of pumps to meet the design flow) would be based on meeting the demand for 16 branch groups plus the machinery space.

Table 9. Nozzle Counts and Design Flow Rates for Flashover Suppression and Extinguishment Objectives Based on Representative Layout on ex-USS *Shadwell*, Frames 15 to 29

| | Flashover Design | Flashover Design | Extinguish (IMO) Design | Extinguish (IMO) Design |
|---|---|---|---|---|
| Area Protected, Frame to Frame | 29 – 22 | 22 - 15 | 29 – 22 | 22- 15 |
| # Nozzles: Main Deck | 22 | 20 | 29 | 22 |
| # Nozzles: Second Deck | 20 | 19 | 28 | 25 |
| # Branch Groups, Main Deck | 10 | 6 | 5 | 5 |
| # Branch Groups, Second Deck | 7 | 6 | 6 | 5 |
| # Nozzles per Branch Group | 3 Note 1 | 3 | 5 Note 1 | 5 |
| Design Pressure, bar | 70 | 70 | 70 | 70 |
| Nominal K factor, L/min/bar$^{1/2}$ | 1.9 | 1.9 | 2.5 | 2.5 |
| Flow per nozzle, L/min (gpm) | 15.9 (4.2) | 15.9 (4.2) | 20.9 (5.5) | 20.9 (5.5) |

*Note 1: With perimeter-mounted nozzles at opposite sides of a compartment, it is more convenient to install separate branch valve connections than to try to connect nozzles in a single branch group. This results in fewer nozzles per branch group for the flashover design than the extinguish design.*

Table 10. Nominal Design Values for Flashover Suppression and Extinguishment Objectives Based on a Generalized Layout for "Typical" Section

| Design Value | Flashover Design | | Extinguish (IMO) Design | |
|---|---|---|---|---|
| | L/min | GPM | L/min | GPM |
| Nozzle Designation / Kfactor (l/min/bar$^{1/2}$) | 4S 1MC 8MB / K = 1.9 | - | 1B 1MC 6MC / K = 2.5 | - |
| Activation means | Open | - | Glass Bulb | - |
| Nominal Flow per Nozzle at 70 bar | 15.9 | 4.2 | 20.9 | 5.5 |
| # of Nozzles / Section | 24 | - | 30 | - |
| # of Branch Groups per Section | 8 | - | 8 | - |
| # of Nozzles / Branch Group | 3 | - | 4 | - |
| Nominal Flow / Branch Group (L/min) | 48 | 13 | 84 | 22 |
| Nominal Flow / Section | 382 | 101 | 627 | 166 |

In Table 11, the calculation is extended to compare the capacity of the pump units that would be required to meet the flashover and extinguishment design demands. The flashover design demand is about 75 percent of the demand for the extinguishment objective.

Table 11. Design Flow Rates for Flashover Suppression and Extinguishment Objectives Based on a Generalized Layout for a Typical Section

| Design Value | Flashover Design | | Extinguish (IMO) Design | |
|---|---|---|---|---|
| Units | L/min | GPM | L/min | GPM |
| Nozzle Designation | 4S 1MC 8MB | - | 1B 1MC 6MC | - |
| Nozzle K factor (L/min/bar$^{1/2}$) | 1.9 | - | 2.5 | - |
| Nominal Flow per Branch Group | 48 | 13 | 84 | 22 |
| Design flow for 8 Branch Groups (Note 1) | 384 | 101 | 672 | 178 |
| Design flow for 16 Branch Groups = Q1 | 768 | 203 | 1,344 | 355 |
| Machinery Room Demand = Q2 (Note 2) | 852 | 225 | 852 | 225 |
| Total Design Flow: *Qdesign*<br>*Qdesign* = sum of Q1 + Q2 Note 2 | 1,620 | 428 | 2,196 | 580 |
| Pump Unit Capacity = 1/3 *Qdesign*<br>*Qdesign* = largest of Q1 or Q2 | 540 | 143 | 732 | 194 |
| Normal system capacity without redundant pump unit: | 1,620 | 428 | 2,196 | 580 |
| Water Demand Comparison (Qdesign/Qextinguish) x 100 % | 74 % | - | 100 % | - |
| Total system capacity, using redundant pump unit | 2,160 | 571 | 2,928 | 774 |

*Note 1:* *Both extinguishment and flashover suppression modes assume 8 Branch Groups per Section.*

*Note 2:* *The total design flow assumes that both the machinery room demand and the Class A fuel area fire demand of 16 branch groups are simultaneous.*

### 3.3 Discussion of Flashover Suppression System Design

The design to meet the flashover suppression rather than the IMO performance objectives has a hydraulic advantage evident in Table 11 in the reduction in the overall water demand, "$Q_{design}$." There will be other advantages, such as reduced installation labor because of fewer nozzles and more compact piping, smaller pump units and possibly further reductions in pipe sizes, with weight and space savings. The flashover suppression design involves slightly more branch group valves per section than the extinguishment design. This arises because, with perimeter-mounted nozzles at opposite sides of the larger compartments, it is more efficient to install separate branch valve connections than to connect all nozzles as a single branch group. The distribution system is based on the sectional loop architecture in both cases, so there would be little difference in recoverability after wartime blast damage. It is possible that nozzles and branch piping mounted close to bulkheads could be less vulnerable to blast damage than nozzles and piping distributed throughout the overhead.

As mentioned in the introduction, the flashover suppression testing described in Reference [1] did not include the full possible range of fuel loads or ventilation geometry for small shipboard compartments. Consequently, the IMO-design approach was recommended for layout on the SHADWELL. It will be possible to convert portions of the system installed on the SHADWELL from the IMO layout to a flashover suppression layout with little difficulty. The FY 01 test program

will incorporate testing with perimeter nozzles, as shown in Figure 13a and 13b, to extend the performance evaluation of the flashover suppression design.

### 3.4 Boundary Area Protection

Both designs for the extinguishment or the flashover suppression objective, permit pre-emptive activation of nozzles on the non-fire side of a compartment boundary. Boundary cooling, or more descriptively, "boundary area protection," is not based on directing sprays directly at bulkheads. Because of the variable locations and size of objects mounted on bulkheads, it would be difficult to achieve a uniform film of water over the entire surface. Instead, the water mist system will be activated on the non-fire side of the bulkhead, to pre-wet class A fuels and cool areas adjacent to a fire compartment. If ignition does occur due to heat conduction at a shielded spot on a bulkhead, the fire growth rate will be slow and limited. In this way, the water mist system will define boundaries to fire spread.

The solenoid actuated branch group valves can be remotely activated to cause mist discharge in any compartment. Part of the FY 00 trial series will involve operating the system in a boundary area protection mode. The decision as to when to activate nozzles in a compartment adjacent to a fire area may be made on the basis of temperature or smoke sensor data.

## 4.0 DISCUSSION OF ALTERNATIVE WATER-BASED SUPPRESSION SYSTEMS

A criticism of the application of a HP water mist system as a general fire protection system on a Navy ship is the cost impact compared to a system supplied from a traditional fire main. A fire main system could supply a traditional marine sprinkler system along with other hydraulic loads. Alternatively, it could supply a LP water mist system if local pressure-boosting pumps were installed throughout the ship. From a commercial design standpoint, HP water mist systems have been demonstrated to be cost competitive with marine sprinkler systems. HP water mist systems are believed to offer greater survivability/ recoverability compared to LP and traditional systems by virtue of their lower space/weight impact (i.e., overall lower impact would allow a greater level of redundancy). LP water mist and sprinkler systems become attractive when the "cost" of the fire main is considered "free" in terms of fire protection. In other words, there are other requirements (cooling water, magazine cooling, exterior wash down) that potentially require a fire main, so its availability for fixed fire suppression systems such as sprinklers is presumed to be cost-free.

From a fire protection standpoint, there are two outstanding needs to be addressed in conjunction with a fixed, water-based suppression system:

1. Manual fire fighting; and
2. Weapons/magazine protection.

With significantly reduced manning, there is a question as to the need for multiple, large diameter fire fighting hoses. The DC-ARM approach is to prevent fire/smoke spread beyond the primary damage area, and recover damaged spaces as quickly as possible. This "recoverability"

aspect must clearly be tied to ORD criteria for other ship systems/characteristics in terms of recovering mission capability. Aggressive fire fighting in the primary damage area by multiple hose teams is not anticipated in the DC-ARM approach. The minimum level of manual hose stream demand must be identified.

Alternatives that address these fire protection needs might result in a decreased reliance on a traditional fire main system, to the extent that alternative distribution systems are viable in terms of cost and ORD criteria. As identified in Appendix A, HP water mist appears to offer a reasonable balance in terms of overall ship impact, fire protection capabilities and survivability/recoverability. A first order, qualitative comparison of attributes between LP water mist/sprinkler systems and HP water mist is shown in Table 12. Additional feasibility analysis is clearly warranted.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

This study undertook the development of a piping system "architecture" that would have certain performance advantages for the distribution of water to a network of water mist nozzles on a Navy ship. The hydraulic distribution system is intended to be able to "self-diagnose" the occurrence of a rupture in the piping and respond automatically to isolate the ruptured area. Three distribution system layouts were investigated:

1. Center Main, with vertical risers connecting deck levels, spaced at 4 per fire zone, with branch group valves feeding branch lines to port and starboard;

2. Dual Main, with parallel mains to port and starboard outboard areas, vertical risers on port and starboard, spaced at 4 per fire zone, and branch group valves supplying branch lines from outboard to mid-ship areas; with the addition of crossover connections, the dual main structure becomes a "Dual Main/Offset Loop" structure;

3. Sectional Loop, with port and starboard mains connected by two crossover mains at each watertight bulkhead defining the limit of each "section." In each fire zone there are four vertical risers from the pump deck level that connect sectional loops on successive deck levels. Branch lines taken from any location around a loop supply the nozzle groups within each section.

Table 12 – Comparison of Alternative Suppression Systems

| Attribute | LP Water Mist/Sprinkler System | HP Water Mist |
|---|---|---|
| Manual Firefighting | | |
| – Can potentially supply multiple large flow handlines | Yes | No |
| – Can potentially supply "quick response" or boundary cooling mop up lines | Yes | Maybe |
| – Seawater required (maintainability issue) | Yes, but could be fresh water charged | No |
| – Tanks required (space/weight issue) | No | No (initial flow from potable water supply) |
| Fire Suppression | | |
| – Flashover Suppression Mode | Maybe | Yes |
| – Extinguishing Capabilities (IMO) | Fair | Good |
| – Automatic, reflexive, remote mode | Difficult | Straight forward |
| – Combined remote and reflexive response | Difficult | Easier |
| – Potential to combine with gaseous system | No | Yes |
| – Water application rate | Higher | Lower |
| – Potential for smoke control/scrubbing | Unlikely | Potentially |
| – Combine with Machinery Space Systems | Unlikely | Yes |
| Weapons Protection | | |
| – Weapons protection | Yes but basis of criteria not clear | Potentially |

Several factors favored the sectional loop architecture over the center main or dual main/offset loop. Favorable properties were described as follows:

1. Hydraulic advantages: the three-dimensional grid with multiple flow paths permits use of relatively small diameter pipe hence increases the capacity for redundant flow paths.

2. The "survivability" of branch groups (e.g., 50 percent per fire zone for the postulated damage) was less dependent on adverse or fortuitous location of the blast damage than Dual Main/Offset Loop designs.

3. The arrangement of separate "cells" with many "smart valves" is expected to simplify recognition and rapid isolation of a rupture.

The advantage of the sectional loop architecture depends on the use of "smart valves" on every section of pipe. This obviously creates a system with many valves, and raises questions of cost and maintainability of the system. Configurations with fewer valves were evaluated, but every reduction was accompanied by an increase in the size of the area isolated to recover from a rupture. The design has proceeded on the basis that the valves are needed because they provide the desired level of system flexibility. Some level of saving is provided by the fact that the distribution system pipe is not large – 40-mm (1 ½ in.) maximum. The concept of designing "valve nodes" which consolidate several valves at an intersection into a more cost-effective unit was presented as a possible means of reducing valve costs. Other means of reducing the cost of valves will be pursued as a future step.

The sectional loop architecture is being installed on the SHADWELL. The test facility includes HP pump units, risers and mains, between Frames 15 and 29. Figure 8d illustrates the partial sectional loop structure, as it appears on the SHADWELL. As the test area between Frames 29 and 15 only represents one-half of a "fire zone," the test system is only part of a full sectional loop structure. Nevertheless, it will incorporate two sectional loops on each of three deck levels, plus the pumping unit level on 4th Deck, and sufficient valving to be able to demonstrate the rupture isolation algorithm. The multi-loop structure will be sufficient to test out the potential advantages of the sectional loop architecture and to compare that performance with other architectures. By closing valves on crossover mains, the piping system can be reconfigured as either Dual Main or Offset Loop arrangements, in order to evaluate the comparative advantages of one arrangement over the other.

It is anticipated that FY 00 DC-ARM demonstrations will exercise the HP water mist system in the remote – manual mode of operation. In other words, personnel will activate system valves to achieve suppression and boundary cooling based on supervisory control system sensor data and logic and DCA judgment. Fully automated systems will be evaluated in FY 01. In terms of the HP water mist system, areas of potential investigation/evaluation include:

1. Implementation of lessons learned in the FY 00 demonstration;

2. System architecture tradeoffs;

3. Extinguishment objectives applied to Navy – particular spaces (i.e., does the IMO criteria fully address all spaces found on Navy ships);

4. Value and implementation of a flashover suppression system as a default system in the event of major battle damage;

5. Need to tailor boundary cooling/boundary protection for particular hazards or mission critical spaces, and associated actuation mechanisms/triggers; and,

6. Investigation of hybrid open/closed nozzles to permit multiple functions.

While R&D continues on the water mist concepts, feasibility evaluations and trade-off studies will continue to determine the optimized strategies for ship-wide fire protection systems in terms of impact, survivability, performance and ability to meet manning-reduction mandates.

## 6.0 REFERENCES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# APPENDIX A – EVALUATION OF A LOW PRESSURE WATER MIST SYSTEM ALTERNATIVE

## A-1.0 INTRODUCTION

This appendix presents the work that was performed to compare the total number of nozzles required, and the overall water flow demands for both a Low Pressure (LP) and a HP water mist system on the ex-USS *Shadwell* (the SHADWELL). Although the systems that formed the basis of this analysis are commercially available, they are referred to in this report only as "the LP system," produced by Manufacturer A, and "the HP system," produced by Manufacturer B.

## A-2.0 WATER MIST SYSTEM DESIGN TO CONVENTIONAL (IMO) SPACING RULES

For comparison purposes, this appendix presents nozzle layouts for an LP (12 bar nominal nozzle pressure) and a HP (70 bar nominal nozzle pressure) water mist system, based on the spacing rules for commercially available water mist equipment. The commercial systems meet the objectives established by the International Maritime Organization (IMO) fire test protocols [A-1]. These objectives exceed the "flashover suppression/boundary cooling" objectives examined in Phase I fire testing [A-2]. Having designed to the IMO spacing rules, it is expected that the resulting water mist system will provide better protection than "only" flashover suppression or boundary cooling. It is expected that most fires will be either extinguished or controlled at a very low heat release rate.

The Phase I fire testing demonstrated that flashover suppression was achievable with low application rates of water mist. The test program did not, however, test the limits to the performance of the system with different compartment sizes, or over a full-range of fuel densities. It was therefore premature to recommend a ship-wide design based on that minimum level of water mist distribution. For the Phase II design that is the subject of this report, the approach taken was to provide a water mist system designed for fire suppression or extinguishment with nozzles distributed throughout the overhead of a compartment in a manner similar to the layout of standard sprinklers.

### A-2.1 Nozzle Layouts

Nozzle layouts were completed for the forward test areas between Frames 15 and 29 on board the SHADWELL following the manufacturers' spacing rules for both the LP and HP systems. The LP system requires a minimum nozzle pressure of 12 bar (175 psig); therefore, most of the distribution system would have to be at a pressure higher than that. NFPA 750, Standard for Water Mist Fire Protection Systems [A-3], would classify this as an "intermediate pressure" water mist system. This study refers to the 12-bar system as "low pressure," however, because it is within the normal operating range of the fire main (~13.8 bar (200 psig)) on Navy ships. Also, it is definitely "low pressure" in comparison with the HP system which involves

system pressures 1000 psig (69 bar) or higher.

Spacing rules for the LP and HP systems are summarized in Tables A-1 and A-2, respectively. The data is taken from the manufacturers' IMO documentation for their marine water mist system listings.

Tables A-1 and A-2 compare the nominal flux density for the LP and HP nozzle types, respectively, as determined by the spacing rules and nozzle discharge characteristics (the "K factor"). Table A-3 is provided to compare these nominal densities to the standard SOLAS marine sprinkler design density of 5.0 $l/min/m^2$ (0.12 $gpm/ft^2$). This comparison was provided so that the relative advantages of using water mist as opposed to standard marine sprinklers can be seen more clearly.

The IMO documents [A-1] refer to "accommodation, public and service spaces and corridors" on ships. For this report, these terms are interpreted as corresponding to "berthing areas, mess, kitchen and storage spaces" on US Navy ships. Compartments are distinguished as "large" or "small" and "corridors" are re-named "passageways." Fire hazards involve "Class A" combustibles. In the marine systems for accommodation, public and service spaces, the nozzles are normally closed, and are thermally activated, i.e., they open when exposed to heat from a fire. Previous studies have examined the use of water mist in machinery spaces on Navy ships [A-4]. Machinery space systems involve Class B combustibles, "open" nozzles and operate in the manner of a deluge system. It is intended that both normally-closed, thermally activated nozzles for Class A fire areas, and "open" deluge-type nozzles for machinery spaces, will be present on the ship.

Nozzle layouts for the forward test areas on Main and Second Decks, Frames 15 to 29 of the SHADWELL are shown in Figures A-1a, A-1b (LP system) and Figures A-2a and A-2b (HP system). The LP system layout resulted in 71 nozzles per deck between Frames 15 and 29. The HP system layout in the same area resulted in 53 nozzles per deck. These sections of the ship near the bow vary in width, so that there are fewer nozzles between Frames 15 and 22 than between Frames 22 and 29. If the ship width were constant, there would be roughly the same number of nozzles in both sections. Although the SHADWELL spaces are specific, the nozzle counts are considered to be representative in general for the two types of systems. In general, then, the LP nozzle layout can be expected to have 40 percent more nozzles per section than the HP system.

The nozzle layouts shown are specific to the configuration of the SHADWELL. To generalize the remainder of this analysis, it is assumed that a "typical Navy ship" will be divided into four fire zones, each 100 feet long. The areas between watertight bulkheads, (for example, between Frames 15 to 22, and Frames 22 to 29 on the SHADWELL), are referred to as "sections." A fire zone 100 feet (30.5 m) long would include four such sections.

Table A-1 – Spacing and Flow Criteria for Marine Applications of Low Pressure Water Mist System Nozzles

| Low Pressure System Criteria | Marine System Data Sheet - Per IMO Resolution A.800.19 | | | | | |
|---|---|---|---|---|---|---|
| IMO Description | Corridors < 1.5 m | Cabins | Cabins | Cabins | | |
| Hazard Equivalent | LH | LH | LH | LH | | |
| Navy Terminology | Passageways | Small Compart'ts | Small Compart'ts | Large Compart'ts | | |
| Compartment area | N/A | Up to 6 $m^2$ | 6 to 12 $m^2$ | 12 to 25 $m^2$ | | |
| Maximum Overhead Height (m) | 2.5 | 2.5 | 2.5 | 2.5 | | |
| Automatic or Open | Auto | Auto | Auto | Auto | | |
| Nozzle Designation | AM6 | AM11 | AM11 | AM11 | | |
| K- factor (constant) L/min/bar$^{1/2}$ | 4.7 | 4.7 | 4.7 | 4.7 | | |
| Discharge @ 12 bar (L/min) | 16.3 | 16.3 | 16.3 | 16.3 | | |
| Max. Spacing (m) | 1.8 m + 0.1 | 1 nozzle | 2.40 (2 noz) | 2.50 | | |
| Distance from walls (m) | Center Line | 1.30 | 1.20 & 1 at door | 1.25 | | |
| Average Nominal Density, l/min/$m^2$ | 5.0 | 2.72 | 2.72 | 2.60 | | |
| | | | | | | |
| IMO Description | Luxury Cabins | Corridors | Public Spaces | Service Areas | Service Areas | Engine Rooms |
| Navy Terminology | Large Compart'ts | Passageways | Large Compart'ts | Storage | Storage | Machinery Rooms |
| Hazard Equivalent | LH | LH | LH | OH-2 | OH-1 | Flam' Liquids |
| Compartment area | 12 - 49 $m^2$ | w > 1.5 m | Area > 49 $m^2$ | No Limit | No Limit | Limit by supply |
| Maximum Overhead Height (m) | 2.5 | 5.0 | 5.0 | 2.5 | 3.0 | 7.5 |
| Automatic or Open | Auto | Auto | Auto | Auto | Auto | Open |
| Nozzle Designation | AM22 | AM22 | AM22 | AM24 | AM24 | AM10 |
| K- factor (constant) (L/min/bar$^{1/2}$ ) | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 3.5 |
| Discharge @ 12 bar (L/min) | 31.9 | 31.9 | 31.9 | 31.9 | 31.9 | 12.1 |
| Max. Spacing (m) | 3.50 | 2.8 | 2.80 | 2.50 | 2.50 | 2.83 |
| Distance from walls (m) | 1.75 | 1.40 | 1.40 | 1.25 | 1.25 | 1.42 |
| Average Nominal Density, l/min/$m^2$ | 2.60 | 7.60 | 4.07 | 5.10 | 5.10 | 1.51 |

Table A-2 – Spacing and Flow Criteria for HP Water Mist System Nozzles for Marine Applications

| IMO Compartment Dimensions | Cabins < 16 $m^2$ | Rooms > 16 $m^2$ | Rooms > 16 $m^2$ | Corridors Width < 1.5 m | | |
|---|---|---|---|---|---|---|
| Navy Terminology | Small Compartments | Large Compartments | Large Compartments, 2 Deck Height | Passageways | Storage Space | Machinery Spaces |
| FM or UL, Land based Terminology | Light Hazard | Light Hazard | Light Hazard | Light Hazard | Ordinary Group 2 | Machinery Spaces |
| Maximum Deck Heights | 2.5-m | 2.5-m | 5.0-m | 2.5-m | 2.5-m | 2.5-m |
| Nozzle Designation [1] | 1B-1MB-6MB | 1B-1MB-6MB | 1B-1MC-6MC | 1B-1MC-6MC | 1B-1MC-6MC | 4S-1MC-8MB |
| Glass Bulb, (GB) or Open (O) | GB | GB | GB | GB | GB | O |
| K-factor, L/min/bar $^{½}$ | 1.35 | 1.35 | 2.50 | 2.50 | 2.50 | 1.90 |
| Discharge at P = 70-bar, L/min | 11.3 | 11.3 | 20.9 | 20.9 | 20.9 | 15.9 |
| Max. distance to bulkhead, m | 2.85 | 1.80 | 1.90 | 1.90 | 1.49 | 2.50 |
| Max. spacing, m | One nozzle/room | 3.50 | 3.75 | 3.75 | 2.65 | 2.50 |
| Max. Coverage area, $m^2$ | 16.0 $m^2$ | 12.3 | 14.1 | 14 L | 7.0 | 6.3 |
| Nominal Density; L/min/$m^2$ | 0.7 | 0.9 | 1.5 | 1.5 | 3.0 | 1.9 |

**1. Nozzle Designation Code: 1B-1MB-6MB or 4S-1MC-8MB**

6MB or 8MB — 6 or 8 orifices surrounding the center jet, B = 0.7-mm diameter, C = 1.0-mm diameter
1MB or 1MC — 1 orifice on center axis, B = 0.7-mm diameter; C = 1.0-mm diameter
1B or 4S — 1 = 120 degree cone angle, thermally activated; 4 = 90 degree cone, open nozzle; B = brass; S = stainless steel

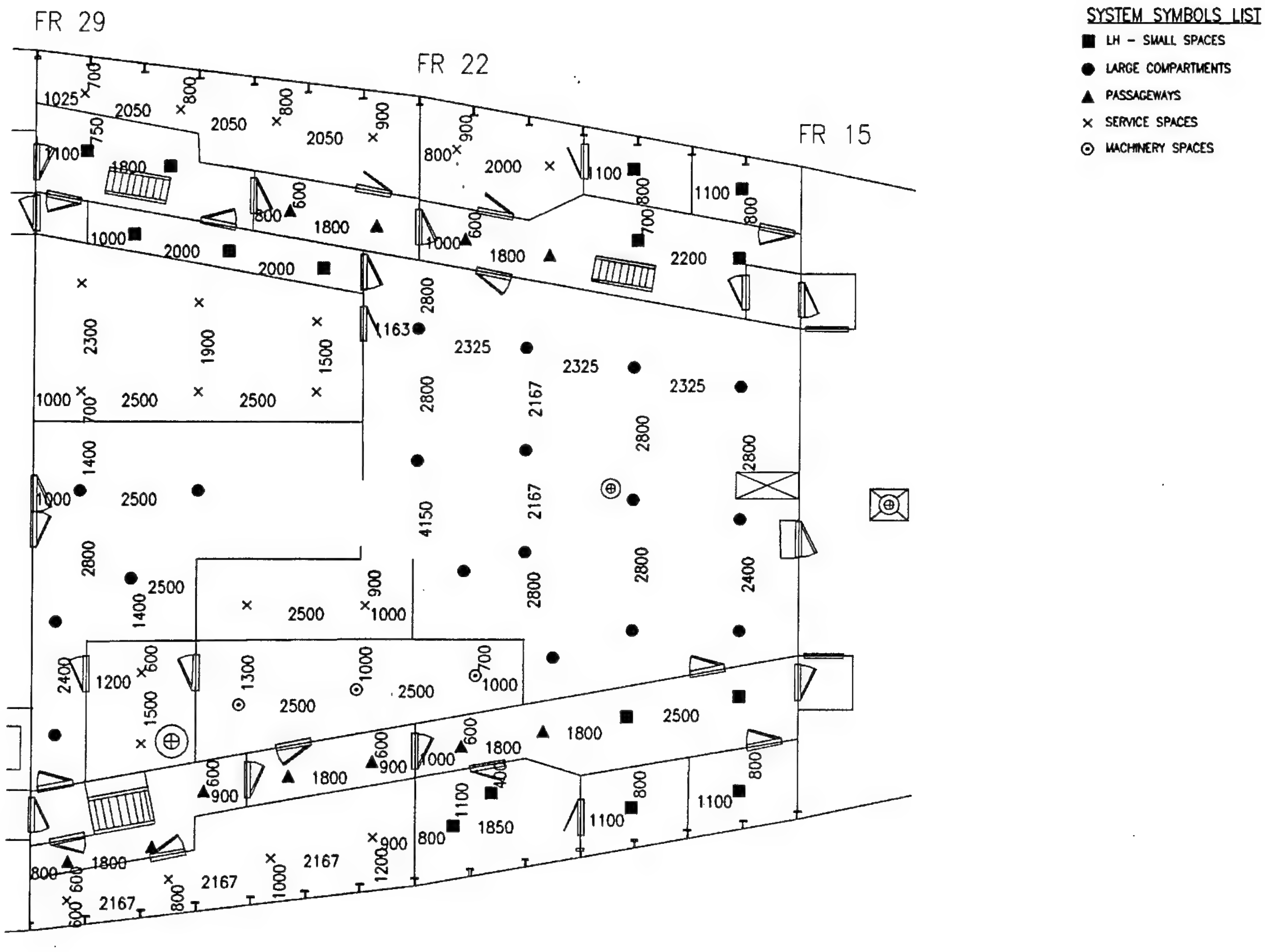


**Figure A-1a LP system nozzle layout, Main Deck ERROR Nozzles, legend**

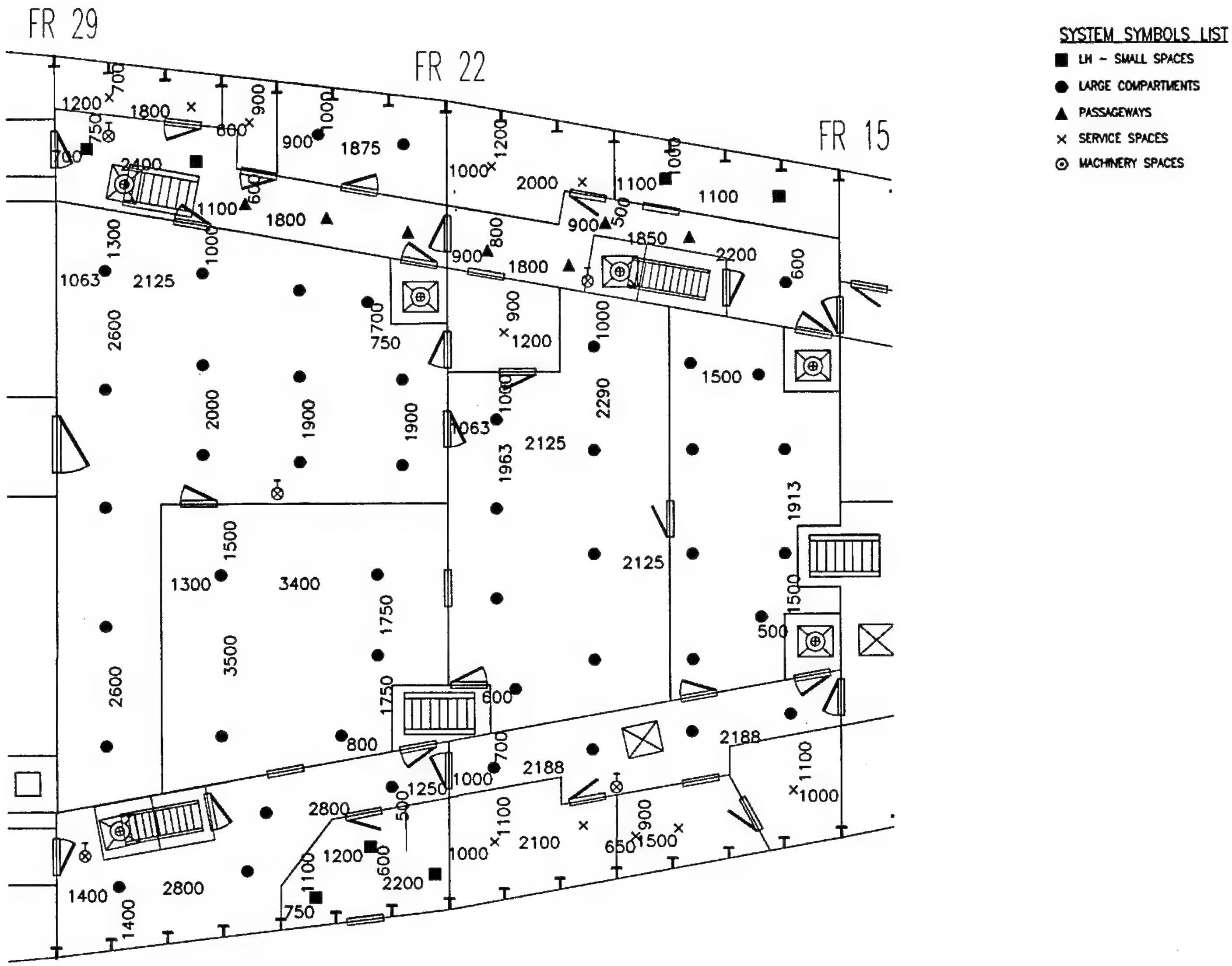


**Figure A-1b LP system nozzle layout, Second Deck ERROR, legend, nozzles**

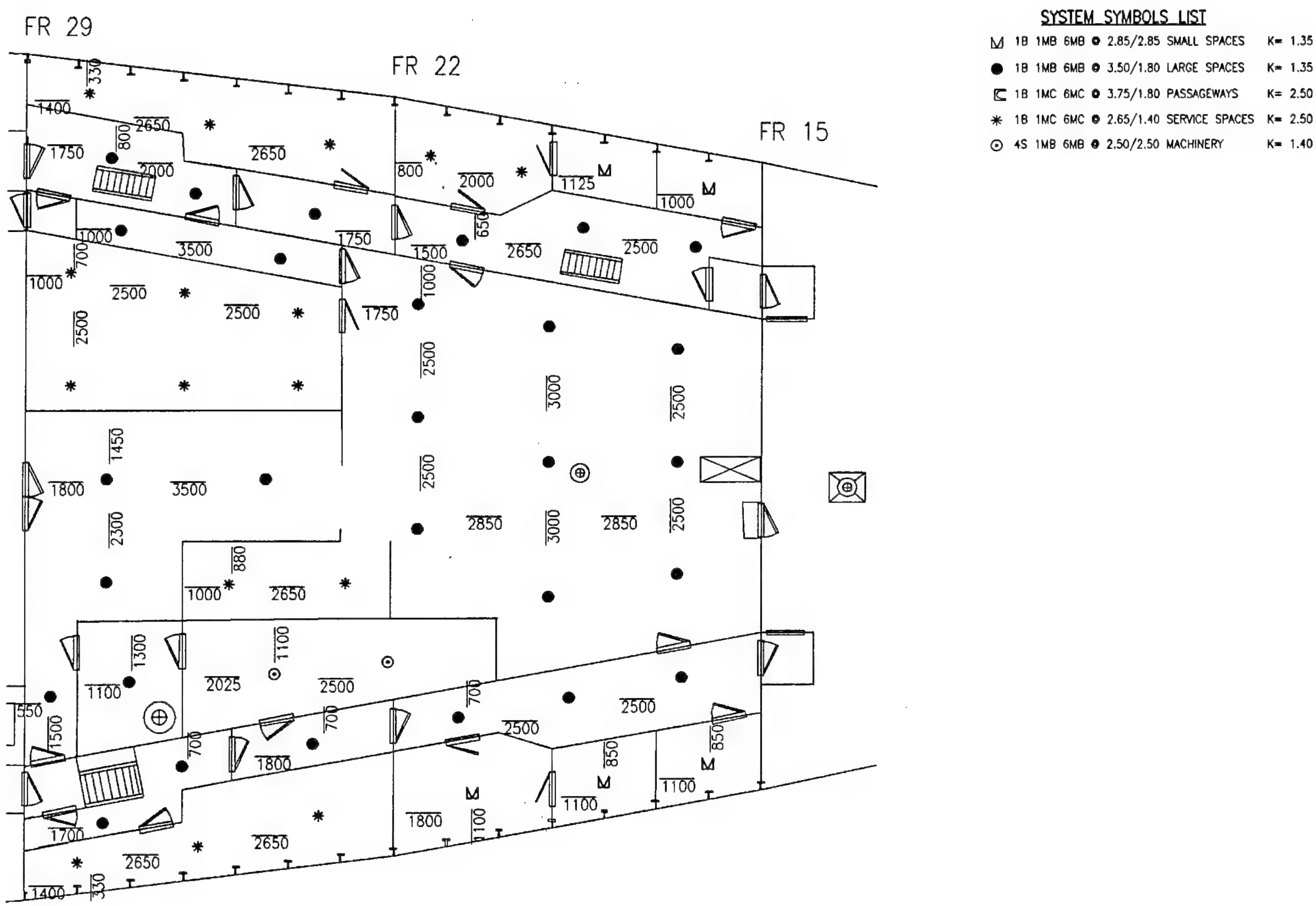


**Figure A-2a HP system nozzle locations, Main Deck of ex-USS *Shadwell*, between Frames 15 and 29**

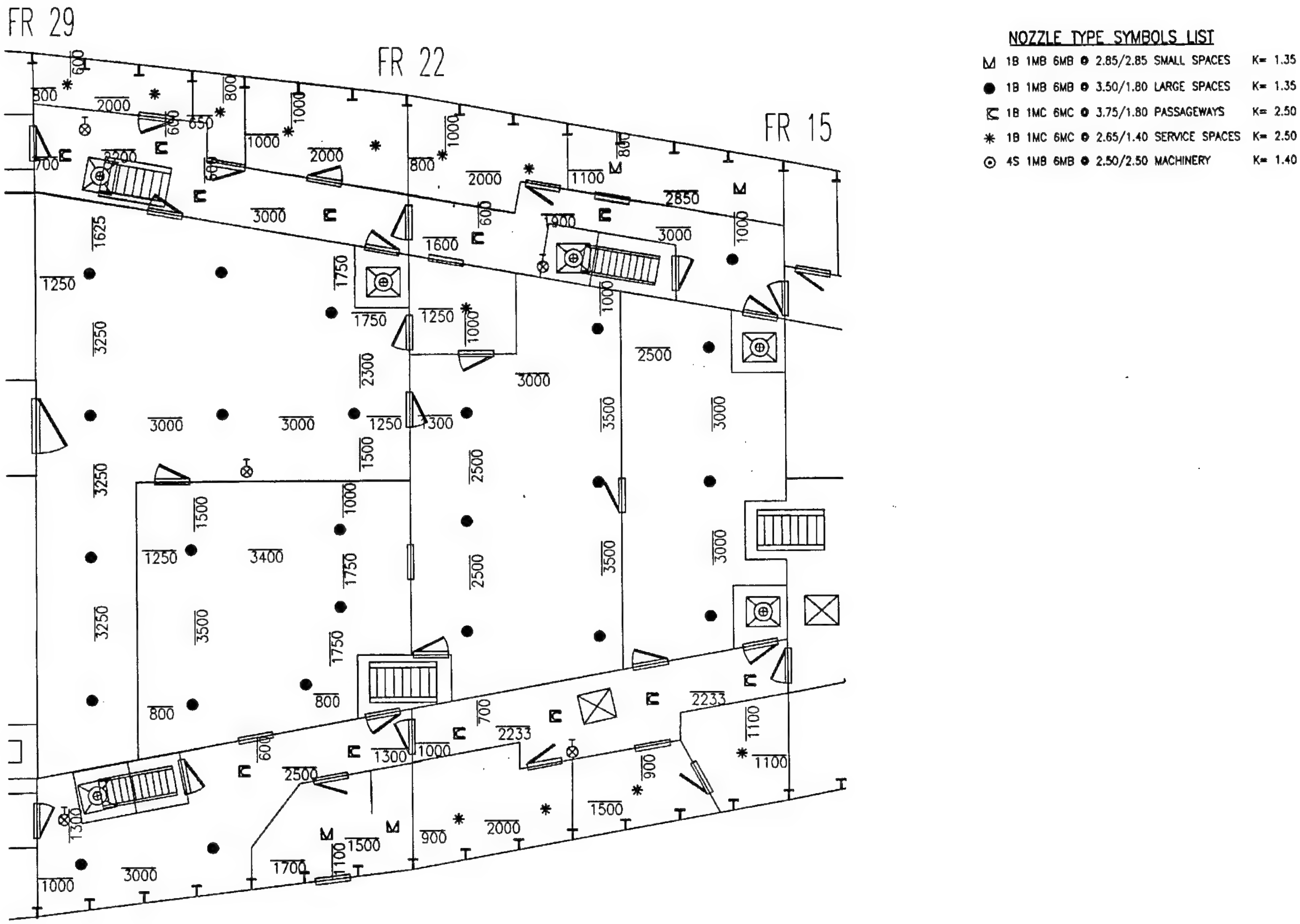


**Figure A-2b HP system nozzles locations, Second Deck of ex-USS *Shadwell*, between Frames 15 and 29**

Table A-3 – Comparison of Nominal Flux Densities for a Range of HP and LP Water Mist Nozzles, to IMO Design Criteria for SOLAS Marine Sprinklers

| Nozzle Designation | LP-1 | LP-2 | LP-3 | HP-1 | HP-2 | HP-3 |
|---|---|---|---|---|---|---|
| K Factor, l/min/m$^2$/bar$^{1/2}$ | 4.7 | 9.2 | 9.2 | 1.35 | 1.40 | 2.50 |
| Minimum Pressure | 12 bar | 12 bar | 12 bar | 70 bar | 70 bar | 70 bar |
| Minimum Discharge, L/min | 16.3 | 31.9 | 31.9 | 11.3 | 11.7 | 20.9 |
| Maximum Spacing, m | 2.4 | 3.5 | 2.8 | 3.5 | 2.5 | 3.5 |
| Maximum Area, m$^2$ | 5.76 | 12.3 | 7.84 | 12.3 | 6.3 | 12.3 |
| Nominal Flux Density, L/min/m$^2$ (gpm/ft$^2$) | 2.72 (0.07) | 2.59 (0.06) | 4.07 (0.10) | 0.92 (0.02) | 1.87 (0.046) | 1.71 (0.042) |
| IMO SOLAS Sprinkler Density, L/min/m$^2$ (gpm/ft$^2$) | 5.0 (0.12) | 5.0 (0.12) | 5.0 (0.12) | 5.0 (0.12) | 5.0 (0.12) | 5.0 (0.12) |
| Percent of IMO SOLAS sprinkler design density | 56% | 53% | 83% | 19% | 38% | 35% |

### A-2.2 Water Demands

Table A-4 compiles the nozzle counts and calculated flow rates for the LP and HP systems using the actual averages for the SHADWELL. Using the total number of nozzles in one section provides a conservative estimate for comparing the typical water demands for the LP and HP systems. The LP system has 36 nozzles per section, whereas the HP system has 26 nozzles per section. Assuming that the nozzles with the largest K factors are installed throughout, and using the minimum nozzle pressure, a nominal design flow rate per section was calculated. The LP demand is 1,148 L/min (303 gpm); the HP demand is 541 L/min (143 gpm). The LP system demand was 2.12 times the HP system demand.

In fact, not all of the nozzles in a Section have the same K factor – nozzles in service spaces and in passageways have higher K factors than nozzles in small compartments. The actual distribution of LP nozzles is 22 nozzles @ K= 9.2; 13 nozzles @ K=4.7; and 1 nozzle @ K=3.5, for an average flow per nozzle of 25.7 L/min. For the HP system, the actual distribution of nozzles is 14 nozzles @ K=2.5, 13 nozzles @ 1.35, 1 nozzle @ K=1.4 for an average flow per nozzle of 16.5 L/min (4.4-gpm). The total flow per section calculates out to 925 L/min (244-gpm) and 489 L/min (129 gpm) for 36 LP and 26 HP nozzles, respectively. Within this more careful calculation, the LP demand is 1.9 times the HP system demand. It is safe to say that with both systems laid out according to their IMO spacing rules, Table A-4 indicates that the LP system requires approximately 40 percent more nozzles and 100 percent more flow than the HP system.

As shown in Table A-3 for the nominal spacings, the water demand for the LP nozzle is at least 56 percent of what would be required for standard marine sprinklers (SOLAS 5.0 L/min/m$^2$).

Table A-4 – Tabulation of Nozzle Counts and Estimated Design Flow Rates for LP and HP Systems, Modeled on the ex-USS *Shadwell*

| DCARM (2/26/99) | Low Press | Low Press | | High Press | High Press | Notes |
|---|---|---|---|---|---|---|
| Comparisons | Frame 29-22 | Frame 22-15 | | Frame 29-22 | Frame 22-15 | LP nozzle average K factor: |
| # Nozzles: Main | 40 | 31 | | 29 | 22 | 23 @ K=9.2, 13 @ K=4.7; 1@ K= 3.5 |
| # Nozzles: 2nd Deck | 36 | 35 | | 28 | 25 | |
| # Br. Groups, Main | 6 | 6 | | 8 | 8 | For HP system, use 8 branch groups each section |
| # Br. Groups, 2nd | 5 | 6 | | 8 | 8 | |
| # Nozzles / Br. Group | 7 | 6 | | 4 | 3 | |
| Design press, bar, (psig) | 12 | (174) | | 70 | (1,015) | End nozzle pressure, bar (psig) |
| Largest K factor, L/min/bar$^{1/2}$ | 9.2 | 9.2 | | 2.5 | 2.5 | Designed for worst case: LP - K = 9.2; HP - K = 2.5, l/min/m$^2$/bar$^{1/2}$ |
| Typical Flow/nozzle, L/min (GPM) | 31.9 | (8.4) | | 20.8 | (5.5) | Flow from largest orifice nozzles, L/min (GPM) |
| Generalized or Average values for "Section" (e.g., Frames 29 to 22) | | | | | | |
| # of Nozzles per Section | 36 | Average | | 26 | Average | |
| Total flow per Section, L/min (GPM) | **1,148** | **(303)** | | **541** | **(143)** | LP demand is 2.1 x HP demand per Section. |
| # of Nozzles / Branch Group | 6 | | | 4 | | |
| # Branch Groups/Section | 6 | | | 7 | | Standardize to 8 Branch Groups per Section, HP. |
| Nominal Flow / Br. Group | 191 L/min | 51-gpm. | | 84 L/min | 22-gpm | |
| Wartime demand, 16 Br. Groups | 3,056 L/min | 807-gpm. | | 1,344 L/min | 355 gpm | See Table 3, main body of report for HP demand |
| Total pump energy requirement to meet wartime demand, kW (bHP) | 92 kW | ( 124 ) | | 235 | ( 316 ) | Nominal pump energy needed to meet all of wartime demand at 1.2 x minimum nozzle pressure. (Each of 4 individual pump units is sized to 1/3 the design flow rate). |

In contrast, the HP system meets the same performance objectives with at most 38 percent of SOLAS sprinkler demand. In a real system, with a variety of nozzle types for different compartments, the LP system demand would be more than 56 percent of marine sprinkler demand, and the HP system less than 38 percent of marine sprinkler system water demand.

A major advantage inherent in reduced water demand can be quantified by determining the nominal system pipe size to "handle" the flow. Pipe sizing in a hydraulic system is typically done through hydraulic calculations that reveal that overall friction losses in the system are within "reasonable" limits, and within the capacity of the water supply. In estimating pipe sizes for both the LP and HP distribution networks, several assumptions were made. The first was that the distribution system would be arranged as a three dimensional grid, with all pipes the same size. This assumption is valid for the sectional loop architecture, but not for the center main or dual main/offset loop architectures, which may require changes in pipe size depending on distance from the pump station. Secondly, a limit on head losses per unit length of pipe was applied (indirectly), by defining a maximum velocity for water flowing through any pipe in the system.

For the LP system, the industry norm is to limit pipe velocity to 7.62 m/s (25 fps), because that is the upper limit stated in NFPA 750 [A-3] for use of the Hazen Williams formula for calculation of friction losses. If pipe velocities exceed that limit, the designer may choose to convert to use of the Darcy Weisbach formulas for calculating friction losses, because it is deemed to more accurately taken into account for turbulence and water quality. In general, the LP system designer chooses to keep velocities below 7.62 m/s (25 fps) so as not to be required to use the more complex calculation method. For HP systems, the industry norm is to use the Darcy Weisbach calculation approach in all cases, and there is a much higher tolerance for system head losses. "Acceptable" head losses for the design condition are determined by economic factors driven by the cost of the pumping system. If pipe sizes are "too small," velocities will be "too high," with associated high-energy losses in the piping, coupled with increased vibration and valve-closure problems. For this analysis, an upper limit on velocity for the HP system was set at 10.7 m/s (35 fps), estimated to correspond to manageable friction losses and system operating conditions.

The design flow rate for purposes of sizing the distribution piping was taken, as the flow required supplying all the branch groups in one section. For the design condition discussed in the main body of the report, i.e., 16 branch groups under wartime damage scenarios; the flow would be distributed fore and aft of the damaged area. Therefore, the total flow for 16 branch groups (which is twice the flow for one section) would not be concentrated in a single leg of the loop. For pipe sizing, the "worst case" was taken, as the condition in which all flow for a single section must come through one riser, or one connection from an adjacent sectional loop. Setting a maximum flow velocity of 7.6 m/s (25 fps) for the LP system, and 10.7 m/s (35 fps) for the HP system, Table A-5 shows the pipe inside diameters and nominal pipe sizes for the LP and HP distribution grids.

Table A-5 – Calculation for Nominal Pipe Size for Distribution Piping, HP and LP Water Mist Systems

| System Type | Maximum Velocity m/s | Maximum Velocity ft/s | Design Flow [1] L/min | Design Flow [1] GPM | Calculated I.Dmin mm | Calculated I.Dmin in. | Nearest Nominal S-40 Standard Pipe Size mm | Nearest Nominal S-40 Standard Pipe Size in. |
|---|---|---|---|---|---|---|---|---|
| LP | 7.62 | 25 | 1,148 | 303 | 56.5 | 2.23 | N-65 | 2 ½ |
| HP | 10.66 | 35 | 541 | 143 | 32.8 | 1.29 | N-32 | 1 ¼ |

*1. For pipe sizing, the design flow was taken as the total demand for one section, on the basis that that is the most flow likely to be forced through a single riser or leg of the distribution system. Total overall system demand is higher than the flow for one section, but flows are distributed over several risers or sectional loops.*

### A-2.3 Pump Requirements

Although the flow rate for the HP system is significantly less than the LP system, the pumping energy required to achieve system-operating pressure is much higher for the HP system than the LP system. As Table A-4 indicates, the LP flow rate and pressure can be met with approximately 46 kW (62 HP) pump energy. The HP system requires 126 kW (169 HP) to meet the performance condition. The numbers are for comparison purposes only, and are calculated based on the following assumptions:

- Pump discharge pressure is 1.20 times the minimum nozzle pressure ($P_n$) to account for head losses between the pump discharge flange and the most remote area,
- Each pump unit is sized to provide 1/3 × the wartime demand (16 branch groups) plus machinery space (see main Report Section 2.3),
- The pump/motor efficiency factor is assumed to be 0.80, and
- Nominal pump energy required (kW) = (Q × 1.20 × $P_n$) / (600 ×0.80).

The minimum nozzle pressure required for the LP nozzle ($P_n$ = 12 bar) is significantly greater than required for a sprinkler nozzle ($P_n \sim 1$ bar). It is not expected, therefore, that the ship's fire pumps, if sized for sprinkler flows, would be able to meet the higher-pressure demand of the LP water mist system. Additional pumps dedicated to the LP system would be required. For these reasons, the LP system appears to provide little if any advantage over standard marine sprinklers.

The HP system requires dedicated HP pumps and a distribution system that are independent of the ship's fire pumps and fire main. Since the design flow rate is about one-half that of the LP system, benefits such as allowing for smaller diameter mains than LP water mist system may be realized. Further reductions in distribution pipe size may be realized if the dedicated HP pumps are selected to overcome higher system frictional losses than normally tolerated with traditional fire pump systems. Smaller pipe sizes permit redundant supply piping and thereby improve survivability under wartime-damage scenarios. For these reasons, the design for survivable system architecture presented in the main body of this report is based on using the HP system.

### A-2.4 Conclusion of LP Water Mist System Evaluation

Layouts for commercially available LP and HP marine water mist systems meeting IMO performance objectives were analyzed for total number of nozzles, total water demand, and the impact of those factors on pumping requirements and distribution system pipe size. Results are summarized in Table A-6. It is concluded that the HP water mist system offers the greatest number of advantages for reduced water flow demand and reduced pipe size, relative to meeting the objectives to the DC-ARM study. The additional pumping energy required by the HP system is deemed to be justified on the basis that the Phase I testing showed that the HP sprays provided better extinguishment and fire suppression potential than the LP sprays.

Table A-6 – Summary of Comparison of Hydraulic Properties of Both Low and HP Water Mist Systems

| | LP | HP |
|---|---|---|
| Total No. Nozzles per Section | 36 | 26 |
| Total Flow (Q) per Section, L/min (GPM) | 1,148 (303) | 541 (143) |
| Nominal System Pipe Diameter based on 10.6 m/s maximum velocity for the HP, and 7.6 m/s for the LP system | 56.5 (2.23)<br>(N -2 ½ ) | 32.8 (1.29)<br>(N – 1 ¼ ) |

### A-3.0 REFERENCES


A-1. IMO Res.A.800 (19) "Revised Guidelines for Approval of Sprinkler Systems Equivalent to that Referred to in SOLAS Regulations II-2/12- Appendix 2- Fire Test Procedures for Equivalent Sprinkler Systems in Accommodation, Public Space and Service Areas on Passenger ships," International Maritime Organization, London, UK December 1995.

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A-3. National Fire Protection Association, "NFPA 750, Standard for Water Mist Fire Protection Systems," National Fire Protection Association, Quincy, MA, 2000.

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